Influence of load management in distribution network on voltages and active power losses: Case Study

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Abstract— **Production of photovoltaic (PV) power plants depends on weather conditions which can cause sudden and often unpredictable variation in their output power. Balancing the production from renewable sources with consumption requires utilization of power plants with fast response or energy storage systems what causes considerable costs. In recent years, in terms of balancing, the emphasis is on the higher role of the consumers. In this paper computer model of the part of distribution network is used to simulate and analyze demand side load management (using air conditioner installed in households) in the distribution feeder considering PV power plant expansion scenarios. Three case studies are analyzed: first with low penetration of PV plants in distribution system, second with moderate penetration of PV power plants and third with high penetration of PV power plants. Influence of demand side load management on network voltages and active power losses is investigated.**

Keywords*— *demand side load management; distribution network; photovoltaic power plant; air conditioner; voltages; losses

I. INTRODUCTION

In recent years, the number of distributed renewable energy sources connected to the distribution network is constantly growing. One of the fastest growing technologies are photovoltaic power plants (PV or photovoltaic) that are often located at the point of consumption (on rooftops) and this way of connection to the power system where power production is located close to power consumption has some advantages such as reduced energy losses, reduced use of the transmission and distribution networks capacity and thus reducing the need for future network investment. On the other hand, production output of some renewable energy sources (PV particular) depends on the variable and less predictable weather phenomena (wind, solar radiation, etc.). Such random production from renewable energy sources can cause the difference between electricity production and consumption, which requires usage of expensive peak power plants for power balancing. In order to overcome the abovementioned problems, there is a new concept in the research and development of electric network called smart grids.

As specified in [1]: “smart grid is the integration of electrical and communications infrastructures with advanced process automation and information technologies within the existing electrical network.” The European Technology Platform for Electricity Networks of the Future, defines smart grid as “an electricity network that can intelligently integrate the actions of all users connected to it-generators, consumers and those that do both, in order to efficiently deliver sustainable, economic and secure electricity supply” [2].

One very important part of the smart grid is demand side load management (DSM) that will allow the management of smart appliances and thus move load from peak periods (when electricity is expensive) to periods when demand is low (when electricity is inexpensive). According to [3], when the full set of different DSM options such as energy efficiency, distributed generation, demand response and storage are used then it is called integrated demand side management (IDSM). According to the [4], 40% of electricity consumption refers to the buildings and therefore household electric appliances have great potential for usage in DSM. There are many suitable electric appliances in the households for DSM such as washing machine, clothes dryer, water heater, air conditioner etc. An intelligent home energy management algorithm for DSM that takes into account load priority and customer comfort level settings can be found in [5].

In this paper, the DSM using the air conditioner is investigated. There has been a lot of research going in the field of using air conditioner for DSM. Authors in [6] present a method for evaluation of the potential effectiveness of a direct air conditioner load control program. A dynamic model of the response of a single residential air conditioner load that takes into account weather conditions is presented in [7]. In some papers like [8], authors present schemes for periodic stopping of air conditioning taking into account human comfort index while in others [9, 10] authors uses programming methods to generate air conditioning scheduling model. Air-conditioning can be used for fast demand side ancillary services as shown in [11]. Practical example of the implementation of the DSM using air conditioning systems can be found in [12]. The aforementioned DSM program “uses a proven technology of radio-controlled switches installed on central air conditioners and heat pumps. During periods of peak electric usage, the switches are activated by a radio signal. This turns the compressor motor off for 7.5 minutes each half-hour” [12].

Two sets of problems regarding DSM of air conditioners in distribution system with photovoltaics are studied and modelled in [13] and [14]. The first problem [13] include local

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DSM in a single building (faculty building) which on the roof has installed a 10 kWp PV system. Five air conditioners located in the main lecture hall, each with rated power of 4.87 kW are used for the modeling of demand response. In the moments when the PV has sudden dips in active power production due to the passage of clouds, DSM is activated (by turning of air conditioners). The objective of the proposed model is to reduce peak demand of the faculty building and thus lowering the cost of electricity. Second problem [14] includes DSM of several family houses that have air conditioners at a 0.4 kV low-voltage (LV) distribution feeder which also contains photovoltaics. The DSM management scheme for coordinated control of household's air conditioners regarding to the production of photovoltaics and electricity consumption of distribution network is presented in [14]. The objective of the proposed model is to reduce peak demand in the distribution network.

This paper presents further work on research showed in [14]. Computer model created in [14] is used to simulate and analyze demand side load management (using air conditioner installed in households) in the distribution system considering photovoltaics expansion scenarios. Three case studies are analyzed: first with low penetration of photovoltaics in distribution system, second with moderate penetration of photovoltaics and third with high penetration of photovoltaics. Input data for case studies are based on measurements results of PV power plant production, household total consumption and air conditioner consumption. Objective is to investigate the impact of DSM on voltages and losses in the distribution network. For every case study, DSM is simulated by shutting down air conditioners in periods when active power supplied from the distribution network is higher than the set point value. Also, scenarios without DSM are simulated for every case study. The results are then compared and analyzed with particular emphasis on voltages in the distribution system and the total losses.

Structure of this paper is as follows: in Chapter 2, a brief descriptions of the studied distribution network and performed measurements are done. The definitions of the demand side load management and case studies are presented in Chapter 3. In Chapter 4, simulation and results for every case study is briefly discussed. A conclusion is given in the last chapter.

II. DESCRIPTION OF THE MEASUREMENTS AND COMPUTER MODEL OD DISTRIBUTION SYSTEM

As an input data for the simulation model, the results of the measurements presented and described in the literature [14] are used. The following quantities are measured: active power production of 10 kWp photovoltaic installed on the family house, total active power consumption of family house and consumption of air conditioner (rated power 700 W) located in the family house. Measurements were performed during the two weeks (from September 1st to September 15th 2014) and one typical day is chosen for further analysis and usage in the simulation model. Measurement results for the aforementioned day and for one family house are presented in Fig. 1. All measurement values are averaged 10-minute quantities.

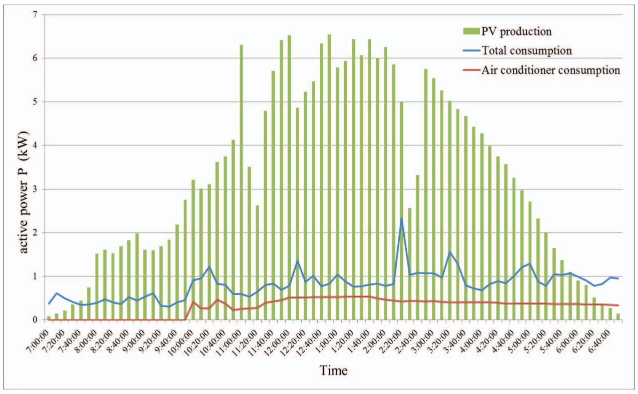

Fig. 1. Measurement results for a choosen day

In this paper, 0.4 kV distribution feeder with 20 family houses supplied from the 10 kV distribution network through the 10/0.4 kV transformer is analyzed. The number of family houses can be modified. It is assumed that every house has one air conditioner (with rated electric power of 700 W) and some of the houses have installed photovoltaic on their roofs (10 kWp) [14]. The number of houses with photovoltaics can be modified according to the PV expansion scenarios. Described distribution feeder together with the photovoltaics is modelled in PowerWorld [15] software package. Part of the PowerWorld model is shown in Fig. 2.

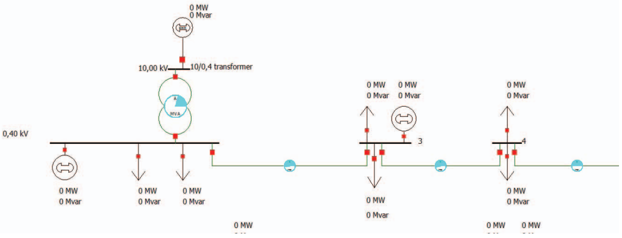

Fig. 2. PowerWorld single line diagram of the modelled distribution feeder

Consumption pattern for air conditioner and family house is modelled as load curves with 72 time points. Every time point presents one 10 minutes measured value. Also, measured data of PV production are used as a generation pattern for modelled photovoltaics. Time frame of modelled load curves is from 7:00 AM to 7:00 PM (there is no need to model whole day because only time period when photovoltaic and air conditioner are active is investigated).

III. DEMAND SIDE LOAD MANAGEMENT SCHEME AND CASE STUDIES

A. DSM

The objective of the DSM proposed in [14] is: "to reduce peaks in active power supplied from the distribution grid when PV power plants are connected. It is assumed that demand side load management is conducted using air conditioners installed in family houses. When active power supplied from the distribution network is higher than the specified threshold, DSM is activated and air conditioners in specific family houses are turned off' [14]. In this way, peaks in active power in the distribution network caused by unpredictable changes in the power output of the PV power plants due to sudden changes in solar irradiation (eg. passing clouds) will be compensated. Detail algorithm for proposed DSM can be found in [14].

B. *Description of the case studies*

In order to investigate the impact of proposed DSM scheme on voltages and losses in distribution network regarding different numbers of photovoltaic connected to the distribution feeder, three case studies are simulated and analyzed:

- Case study A – it is assumed that three (3) houses connected to the feeder have installed 10 kWp photovoltaics. This case study represents low penetration of photovoltaics in distribution system.
- Case study B – it is assumed that five (5) houses connected to the feeder have installed 10 kWp photovoltaics. This case study represents moderate penetration of photovoltaics in distribution system.
- Case study C – it is assumed that seven (7) houses connected to the feeder have installed 10 kWp photovoltaics. This case study represents high penetration of photovoltaics in distribution system.

IV. SIMULATIONS OF CASE STUDIES

A. *Case study A*

First, 72 successive simulations of power flows without DSM for every 10 minutes from 7:00 AM to 7:00 PM are made. Specific time frame is chosen because this is the period when photovoltaics produce according to measurement results (for one typical day in September). Then, simulation is repeated but with DSM on. When active power supplied from the distribution network is higher than 50 kW (threshold specified for the case studies), DSM is activated and air conditioners in family houses are turned off. Active powers supplied from the distribution network when DSM is activated as well as when DSM is deactivated are presented in Fig. 3.

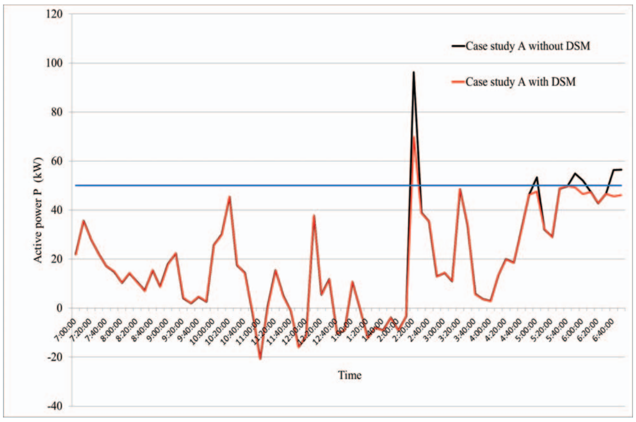

Fig. 3. Active power supplied from the distribution network in Case study A

As can be seen from the Fig. 3, DSM is activated in five time points and the active power peaks are reduced below 50 kW in all cases except one. Uncompensated peak is the result of increased consumption of family houses and in this Case study it can't be reduced below the threshold only by shutting down air conditioners.

Fig. 4 shows simulated rms voltage at bus number ten when simulation is performed with and without DSM. As can be seen from the figure, when DSM is activated, rms voltage of selected bus is higher.

Fig. 4. Voltage at the bus 10 for simulations with and without DSM in Case study A

Active power losses (total for the whole modelled distribution feeder) when simulation is performed with and without DSM are presented in Fig. 5. As can be seen from the figure, losses are reduced for the periods when DSM is activated due to reduction in total consumption (air conditioners are turned off).

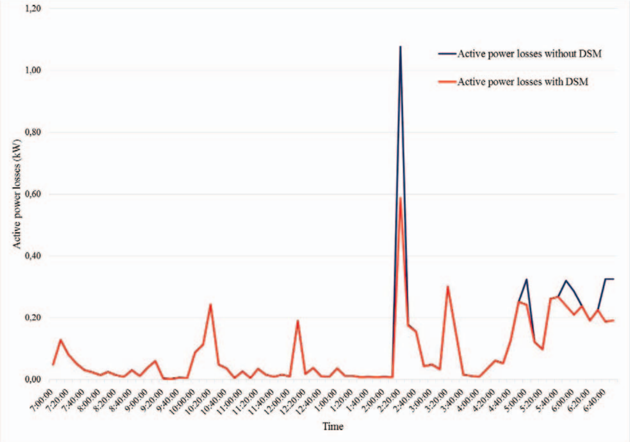

Fig. 5. Total active power losses for Case study A with DSM on/off

B. *Case study B*

The same two simulations as well as in the Case study A were made. The only difference is that the number of PVs is increased from three to five. Active powers supplied from the distribution network when DSM is activated as well as when DSM is deactivated for the Case study B are presented in Fig. 6. As can be seen from the Fig. 6, there are time points when total production of photovoltaics is higher than total consumption of all family houses attached to the distribution feeder and active power is flowing to the distribution network (time points with negative active power). Due to larger number of PV power plants, load peaks caused by family houses are reduced compared to the Case study A. DSM is activated in three time points and all active power peaks are reduced below 50 kW in all time points.

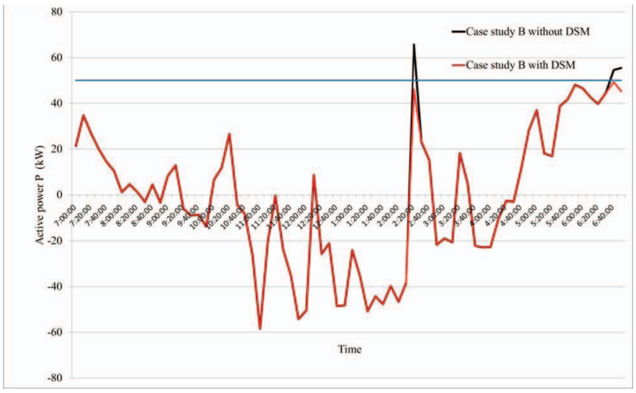

Fig. 6. Active power supplied from the distribution network in Case study B

Fig. 7 shows simulated rms voltage at bus number ten when simulation is performed with and without DSM. As can be seen from the figure, when DSM is activated voltage is slightly raised. Also larger number of PVs slightly rise voltage in all time points compared to the Case study A.

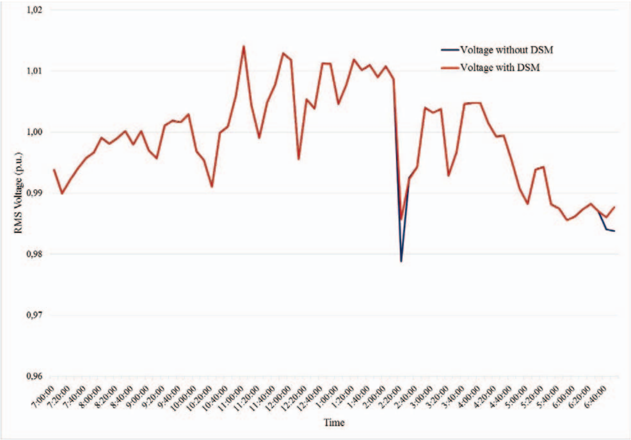

Fig. 7. Voltage at the bus 10 for simulations with and without DSM fin Case study B

Active power losses when simulation is performed with and without DSM are presented in Fig. 8.

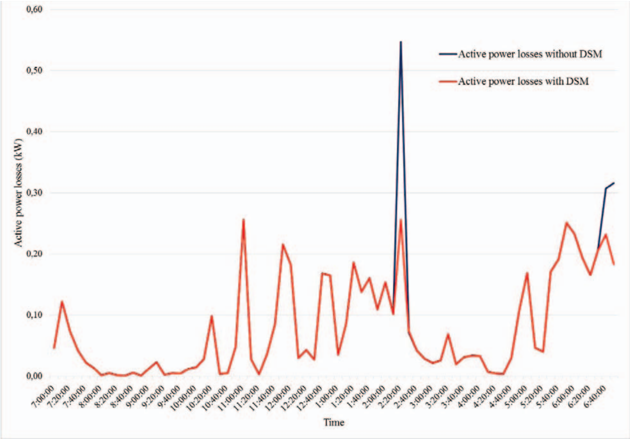

Fig. 8. Total active power losses for Case study B with DSM on/off

As can be seen from the figure, losses are reduced for the periods when DSM is activated due to reduction in total consumption (air conditioners are turned off). Also, active power losses are reduced due to higher penetration of PVs.

C. *Case study C*

This case study represents highest level of photovoltaics penetration (every third house has installed 10 kWp photovoltaics). Active powers supplied from the distribution network when DSM is activated and when DSM is deactivated for the Case study C are presented in Fig. 9. Most of the time, total production of photovoltaics is higher than total consumption of all family houses attached to the distribution feeder and active power is flowing to the distribution network. In addition the limit of 50 MW is several times exceeded in the moments when power flows to the distribution network (in the periods when active power is negative). Shutting down air conditioners in those moments would not lower the negative peak (it will raise the negative peak) and therefor DSM is not activated. It is activated only in two last time points.

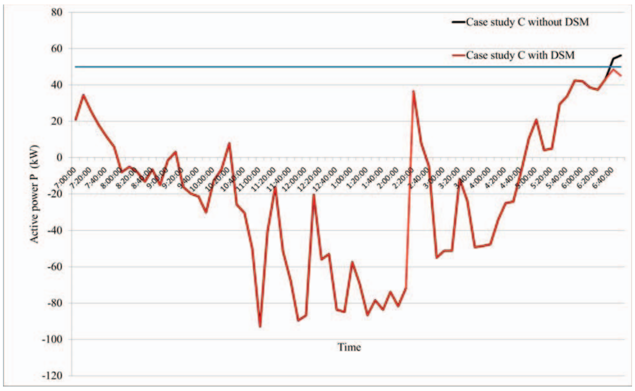

Fig. 9. Active power supplied from the distribution network in Case study C

Simulated rms voltage at bus number ten when simulation is performed with and without DSM is shown in Fig. 10. In the Case study C, voltage is higher compared to the Case study A and B. The reason is the large number of photovoltaics.

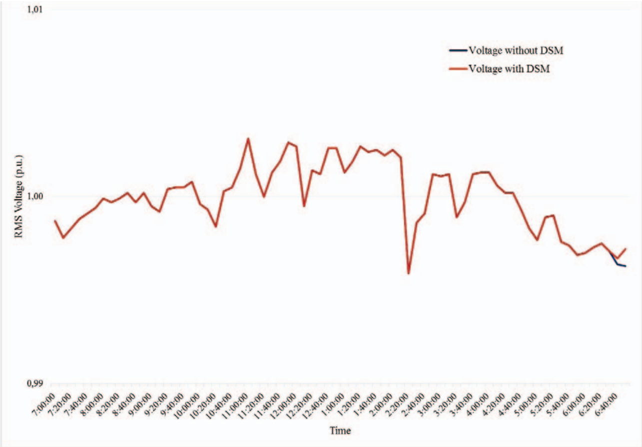

Fig. 10. Voltage at the bus 10 for simulations with and without DSM in Case study C

Active power losses in Case study C when simulation is performed with and without DSM are presented in Fig. 11.

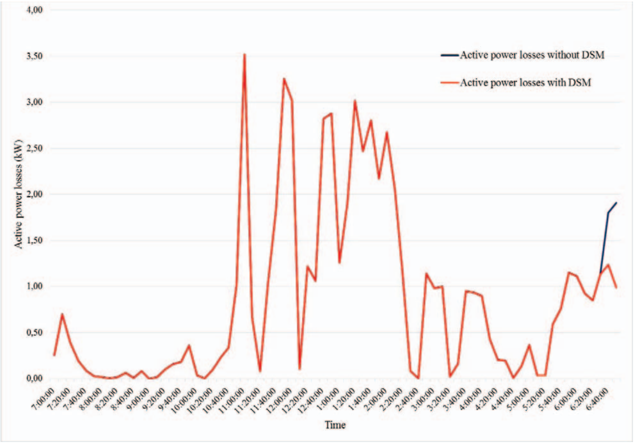

Fig. 11. Total active power losses for Case study C with DSM on/off

As can be seen from the Fig. 11, losses are significantly higher for almost all time points regardless of whether or not DSM is activated compared to Case study A and B. Local loads connected to the feeder can't consume all the energy produced from the photovoltaics and the significant amount of energy is flowing to the distribution network causing significant losses. In this Case study, energy storage device should be included in DSM in order to lower negative peaks and active power losses (energy storage device is not modelled and analyzed here).

V. CONCLUSION

Computer model of the part of distribution network is used to simulate and analyze demand side load management (using air conditioner installed in households) in the distribution feeder considering PV expansion scenarios. Three case studies are analyzed: first with low, second with moderate and third with high penetration level of photovoltaics in distribution system. Influence of DSM on network voltages and active power losses is investigated. Results shows positive influence of DSM on network voltages (it reduces voltage dips caused by the sudden drops in PV power plant production) in all case studies. Also, the increased penetration of photovoltaics, causes voltage rise also in moments when DSM is not activated. All three case studies shows that DSM has positive impact on active power losses. They are reduced every time when DSM is activated. In the case studies with low and moderate levels of photovoltaics penetration, active power losses are reduced also in the hours when DSM is not activated. On the other hand, in the Case study C (highest penetration level), active power losses are increased as well as peaks in active power that flows to/from distribution network. In order to solve the above mentioned problems, the next step will be to model the energy storage device that will increase the flexibility and usability of the DSM. This research is starting point for further work in which optimization model for active power loses minimization in distribution network with DSM will be developed.

REFERENCES

[1] S. Borlase, Smart grids: Infrastructure, Technology and Solutions, Boca Raton, FL: CRC Press, 2013.

[2] European Technology Platform for the Electricity Networks of the Future, official web page, [Online] Available: http://www.smartgrids.eu/

[3] E.C. Woychik, Integrated demand side management cost effectiveness framework white paper, Black&Veatch Corp., for the California Integrated Demand-Side Management Task Force, 2011.

[4] World Business Council for Sustainable Development, "Transforming the market energy efficiency in the buildings", WBSCD, Tech. Rep., June 2009.

[5] M. Pipattanasomporn, M. Kuzlu, and S. Rahman, "An Algorithm for Intelligent Home Energy Management and Demand Response Analysis", *IEEE Trans. Smart Grid*, vol. 3, issue 4, pp. 1704-1711, Dec. 2012

[6] M.W. Gustafson, J.S. Baylor, and G. Epstein, "Estimating air conditioning load control effectiveness using an engineering model", *IEEE Transactions on Power Systems*, vol. 8, no. 3, Aug. 1993.

[7] D. Bargiotas, and J.D. Birdwell, "Residential Air Conditioner Dynamic Model for Direct Load Control", *IEEE Transactions on Power Delivery*, vol. 3, no. 4, Oct. 1988.

[8] S. Liu, C. Chen, and W. Duan, "The Research on Technology of Periodic Stopping of Central Air Conditioning Based on Modeling and Simulation of Demand Response", *in Proc. 2012 China International Conference on Electricity Distribution (CICED 2012)*, Shanghai

[9] C.-M. Chu, T.-L. Jong, and Y.-W. Huang, "Mitigating DLC Constraints of Air-conditioning Loads Using a group-DLC Method", *in Proc. 2007 IEEE Power Engineering Society General Meeting*

[10] C.-M. Chu, and T.-L. Jong, "A Novel Direct Air-Conditioning Load Control Method", *IEEE Transactions on Power Systems*, vol. 23, no. 3, Aug. 2008.

[11] J.H. Braslavsky, C. Perfumo and J.K. Ward, "Model-based feedback control of distributed air-conditioning loads for fast demand-side ancillary services," in Proc. 2013 52nd IEEE Conference on Decision and Control, Firenze

[12] City of Columbia, Missouri, "Load Management", [Online] Available: https://www.como.gov/WaterandLight/Home/load.php

[13] Z. Klaić, D. Šljivac, K. Fekete, and Z. Kraus, "Load Management Scheme Using Air Conditioning Electric Power Consumption and Photovoltaic Power System Generation", *Journal of Energy and Power Engineering*, vol. 8, pp. 1926-1932, 2014

[14] Z. Klaić, K. Fekete, and D. Šljivac, "Demand side load management in the distribution system with photovoltaic generation", *Technical Gazette*, vol. 22, no. 4, pp. 989-995, 2015

[15] Power World Simulator, URL: http://www.powerworld.com/