IMPACTS OF LARGE-SCALE INTEGRATION OF PV BASED GENERATIONS IN A MESH-CONNECTED LOW VOLTAGE NETWORK

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ABSTRACT

In the recent years more and more photovoltaic (PV) panels are being installed at various low voltage (LV) customers' installations that are connected to the public network. As a result, the conventional unidirectional power flow is being gradually changed to a bidirectional power flow which might have significant impact on the network's voltage quality. In the coming years, Endinet, as a network operator, has to face this challenge too and should adapt its present network infrastructure as per predicted needs. Endinet has a mesh connected LV network to deliver reliable good quality electric supply to the customers. This type of network infrastructure is not very common in the Netherlands. Therefore, the impact of large-scale integration of PV panels in such type of meshed network is not very well known. In this paper, the simulation results of a typical mesh connected LV network are discussed for different scenarios of PV panels integration in the grid. From analysis, the loading of various network components and network's voltage quality at various node points are forecasted.

INTRODUCTION

In different countries of the world, governments are encouraging to increase the use of more sustainable based energy sources for electricity generation. During the last decade, large number of decentralized generations (DGs) such as photovoltaic (PV) panels are being installed at the low voltage (LV) customers' installations. Therefore, the customers are not only energy consumers but are electricity producers too. As a result, the conventional unidirectional power flow is being gradually changed to a bidirectional power flow which may influence the network's present voltage quality level. Additionally, the consumer's load demand profile is also changing because of the usage of large number of power electronic devices and increasing number of new loads such as heat pumps and electric cars. In this changing electricity supply-demand environment, every network operator has an obvious target to minimize network losses, maintain network's voltage quality optimally within the standard's specified limits and keep the protection of the network effective.

In the Netherlands, LV networks can be of two typical configurations: radial or meshed. Most of the LV networks (400V- 3 phase, 4 wires) in the Dutch grids operate as radial networks because of the ease of their operation. On the other hand, a mesh connected network enhances the reliability of the network service as it allows the load current to flow in a feeder through more than one route. In addition to reliability of service, a network operator needs to guarantee a supply voltage at a customer's terminal that meets the requirements of EN50160 standard [1]. Under the normal operating condition, supply voltage at all nodes in the LV-network should be within 230V±10% for 99% of the operating time and the lower voltage limit of 230-15% for 100% of the operating time.

A typical generation profile of a PV based DG is often difficult to predict accurately as it depends on the local weather conditions. The electricity production from a PV panel is also dependent on the rotational direction of the sun with respect to the placement of PV panels in a neighborhood and the presence of cloud in the sky. All these uncertainties make it difficult to predict correctly the electricity generation profile from a PV based DG and its impacts on the network's performance: such as voltage profiles at different node points, loading of different network components, network losses, etc. over a period of time. Fig. 1 compares the power production profiles from a group of PV panels located in a street for a clear sunny day and a partially cloudy day. It can be noticed that the electricity production from a PV panel fluctuates significantly when clouds move fast in the sky, covering the sun frequently. Those fast variations of power production can influence the supply voltage rise and also to voltage variations at different node points. Hence, it may have a negative impact on the voltage quality in the network.

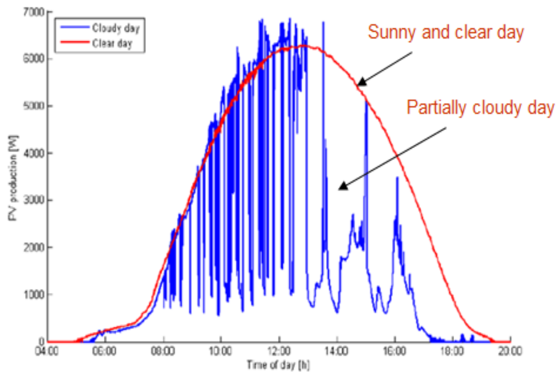

Fig. 1: Daily power production profile from solar panels

In this paper, a realistic mesh connected LV network is considered for analysis. In the test network it is assumed that most of the household customers have PV panels at their installations (using a maximum of 50 m^2 of roof area of each house). Simulations are done with various supply-demand conditions and the performance of the test network (such as loading of various network components and voltage profiles and voltage variations at different nodes) is investigated. Further, an analysis is done to find out the minimum infrastructural changes that are needed (for example: implementing a new cable, or a larger capacity transformer, or requirement of control of load/generation) to accommodate maximum amount of electricity generation from the connected PV panels to optimize the network's supply-demand profile.

TREND OF PV PANELS GROWTH IN ENDINET'S NETWORK

Endinet is a utility company in North Brabant province of the Netherlands and owns the electricity network of the city in Eindhoven. Presently there is no special connection rule in the Netherlands when a household customer wants to install PV panels at his own installation. He may declare his PV panel's production capacity in a dedicated website that is meant for registering all the local generations. From that database it was observed that an increasing number of PV panels have been connected in Endinet's service area during last couple of years, as indicated in Fig. 2. Also, the sharp decrease in the price of PV panels and energy tax reduction benefit from the government encourage more number of household customers to deploy PV panels at their installations. It is expected that in the coming years this growing trend of PV panel integration in the network will remain. Hence, the customer's role as a "prosumer" will be more visible and important to the network operator. The customers will more actively influence the dynamics of the supply-demand graph of electricity in the network.

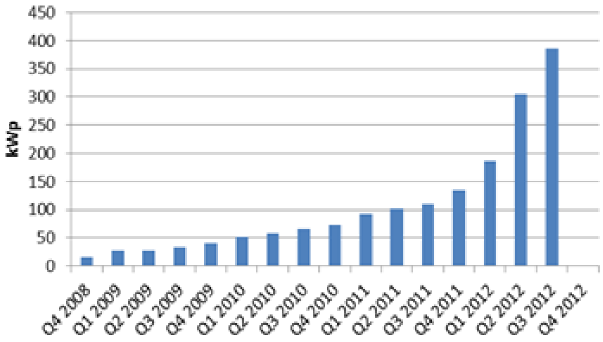

Fig. 2: Growth of connected PV panels in Eindhoven

LOAD DEMAND PROFILE OF A CUSTOMER

A typical household load consumption pattern is generally predictable and a typical characteristic can be obtained from the monitoring data. Fig. 3 describes a summer day and a winter day load demand profiles for a typical household customer. On average a typical household customer consumes 3200kWh electricity in a year. The short-time maximum demand for a household can reach as large as 1.5 kW. However, when a group of households are considered together, the average maximum demand is quite low. This is due to the coincidence factor for simultaneous usage, which is generally low (around 0,1) in a household neighbourhood. The load profiles of Fig. 3 are further considered in this paper for simulation of different case studies.

In the future, with the integration of more number of electrical vehicles in the network, the dynamics of load profile (such as maximum load, coincidence factor, annual growth, etc.) can change significantly. This is mainly due to the different charging characteristics of electric vehicles and the consumer's behavioural of usage. In this paper, the EV loads are not considered.

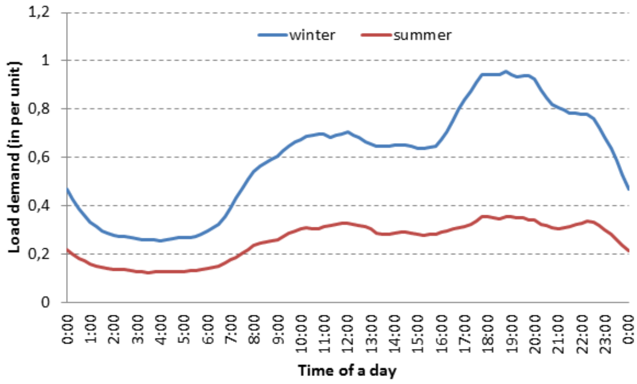

Fig. 3: Typical summer and winter load profile of a household

MESHED LV NETWORK

Every installation in a typical mesh connected network can get electric supply from more than one source. This increases the reliability of the power supply and minimizes the outage time for the customers. During a system disturbance (such as a fault in a feeder), the faulted part can be isolated and the electric supply can still be maintained to the majority of the customers connected in the network. It is expected that with a meshed network structure, the operational losses of the network will be less than in a radial network. However, the short circuit current is generally larger and protection schemes are more complex in comparison to a radially connected network. In a meshed network, the cables are typically loaded up to a maximum of 50% of the rated capacity, considering the philosophy of network's operational reliability. With the connection of many PV panels at different customer's installations in a feeder, the voltage profile and the current loading will be changed. This will have impact on the protection system in the network too. According to the EN50160 standard, voltages (every 10 minutes r.m.s value) at different node points should be limited to ±10% of the nominal value for 99% of the operating time. Moreover, the maximum value of voltage at a customer's installation is to be restricted to U_n+10% for 100% of the operating time, where U_n is the nominal supply voltage. This limit is to avoid damage of the customer's devices because of overvoltage. When power productions from PV panels vary simultaneously, they cause voltage variations too. From literature study [2], it is found that voltage rise is an important issue with large penetration of PV integration in the network, while voltage variation (leading to flicker) is generally not a big problem.

In addition to above limits of voltage conditions, all the cables and station transformers loading should not exceed their nominal rating to avoid thermal damage and reduction of their operating life-span.

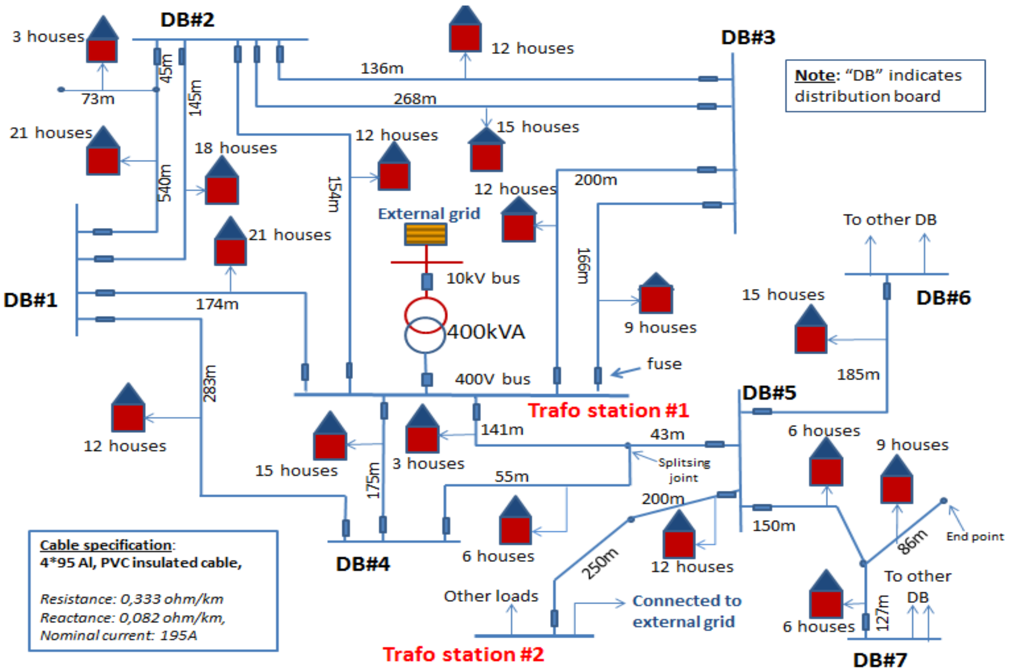

Fig. 4: Part of the meshed network considered for simulation

Fig. 4 shows a part of a LV network considered for simulation. It can be noticed that every distribution board (DB) is fed from two supply sources (or is connected to other DB) to ensure reliability of supply. The total number of houses that are fed by a cable is considered as lumped load and is assumed to be connected at the middle of the feeder (as shown in Fig. 4). An area of 50 m^2 of each house's roof area is used for connecting PV panels. It is assumed that all PV panels are south faced and get similar amounts of solar radiation. Hence, the electricity produced by each household is assumed to be same. The peak electricity production of a PV panel is assumed to be approximately 80W/m^2. On average, the peak power produced by a household is 3.75kW. The power production profiles from PV panels are considered of similar pattern as shown in Fig. 1. Each house is assumed to have a 3 phase 25A connection capacity and the loads and PV panels are distributed evenly in the three phases. The customer's summer load demand is considered in simulation to estimate the maximum impact of PV panels' productions in the network. Two different scenarios are considered to estimate the network's performance.

<u>**Scenario 1:** Maximum generation from PV panels in a sunny day (and minimum load demand)</u>: This case study is to check if the existing capacity of cables and station transformer is sufficient to exploit all the generations from the PV panels. An overvoltage problem in the network can appear when all PV panels are producing at their full capacity. Hence, the rise of voltage levels at all node points in the network is to be checked.

<u>**Scenario 2:** Generation from PV panels in a partially cloudy day (and minimum load demand)</u>: This case study is to check the maximum value of voltage variations at different nodes that are caused by large variations of power productions from the PV panels. The large variations in power productions can occur because of the fluctuations of solar radiation due to the fast moving clouds.

SIMULATION RESULTS

The test network is simulated in Gaia software developed by 'Phase to Phase BV', the Netherlands). In this software an analysis can be done for a specific period, using load demand and PV production profiles. From the simulation of scenarios, it is found that some of the nodes (such as DBs and customer's installations) have overvoltage problem as indicated in Fig. 5. Also, the simulation with daily load and PV generation (fictitious) profile for a cloudy day indicate that there can be many variations in node voltage values, as shown in Fig. 6. Table 1 gives the maximum value of fast voltage variations between two consecutive 10 minutes values at different node points. In this particular case, all the DBs exceed the fast voltage variation limits of 3% which might cause flicker. However, there are no problems measured with flicker in relation to PV yet in practice [2].

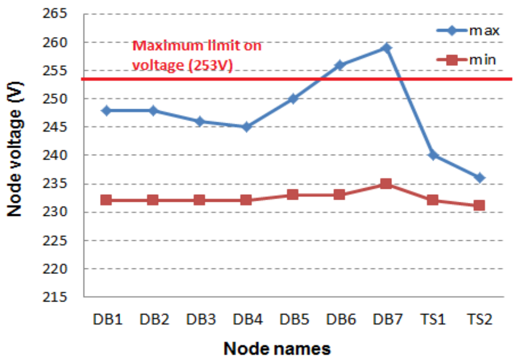

Fig. 5: Maximum and minimum voltages at different nodes for different PV productions scenarios

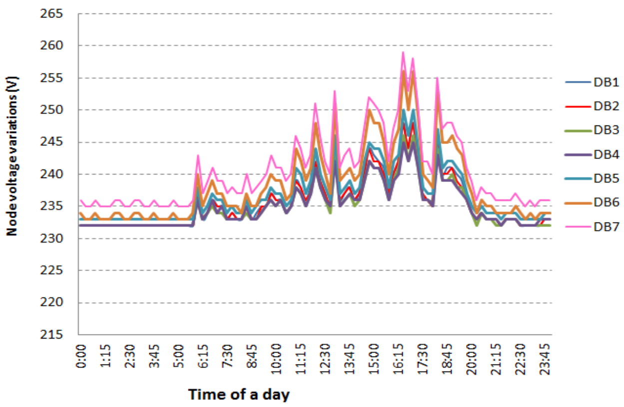

Fig. 6: Voltage profiles at different nodes for simulation with a cloudy summer day PV production profile

Table 1: Maximum variation between two consecutive voltage values at different distribution boards

Node name	DB1	DB2	DB3	DB4	DB5	DB6	DB7
Voltage (V)	10	8	10	11	9	15	15

Moreover, it was noticed that three cables connected between a) transformer station (TS) #1 and DB1; b) TS#1 and DB2 and c) TS#1 and DB5 respectively are highly loaded, exceeding their nominal current carrying capacity limits. The maximum loading of cable is around 140% of the nominal rating, depending on PV productions from the panels. It was also observed that the station transformer becomes overloaded (almost 150% of its rated capacity). In this analysis, simultaneous factor of power production from PV panels is considered as 1. However, in reality, this factor will be lower than 1, because of the actual location of PV panels and their relative exposure to solar radiation. When simulation is done with a simultaneous factor of 0,5 for PV panels (which means 50% of the panels are producing power), it is found that the existing network fulfils all the voltage and loading condition limits.

CONCLUSIONS

The rapid growth of PV panel's connections at the customer's installations will change the power flow direction in the network. To prepare for the future changes, an analysis is done with a part of a typical mesh connected low voltage network, taken from Endinet's service area. Two scenarios are simulated in which all the customers are assumed to have PV panels at their installations. It is observed that when all the connected PV panels (an area of 50m^2 at each house roof) produce electricity at their full power, the existing network would not be able to fulfil the voltage conditions of standard EN50160. An overvoltage problem will occur at different node points. Moreover, station transformer and some of the feeding cables will also be overloaded. Alternatively, if PV panels are installed selectively so that simultaneous factor becomes 50% or lower than the considered value, then the network components overloading problem can be solved and the voltage profiles at different nodes would be improved. Besides that the modern PV panels with a built-in voltage sensor can be installed that can sense voltage condition at its terminal and accordingly switch on and off or will control the amount of PV-power to adjust generation from the panel. In the coming years, definite connection rules will be needed to protect the customer's installation as well as to avoid damage of the network components. To harvest all PV based generations, local storage might also be an option. More analysis is required to explore other possibilities for the optimum utilization of the network. Furthermore, Endinet is planning to start a pilot project in the near future in which all houses in a neighbourhood will be installed with PV panels. A continuous power quality measurement is planned to survey the network and gain expertise about PV panels implementation in the network.

REFERENCES

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[2] B. BLETTERIE, T. PFAJFAR, 2007, "Impact of photovoltaic generation on voltage variations – how stochastic is PV?", *19th International Conference on Electricity Distribution*, CIRED 2007, Vienna.