Implementation of Peak Demand Reduction on a Distribution Feeder using Python-OpenDSS co-simulation

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***Abstract*— In India, the power distribution is the weakest and the most crucial segment in the power system. The major problem faced by the power distribution sector is the management of peak load. Peak load condition leads to electric power interruption which brings down the consumer satisfaction. The proposed work focuses on prevention of peak load on urban distribution feeder. This situation may occur for small duration at any time in a day. The work includes monitoring for peak load condition on the distribution feeder. On occurrence of peak load, an automatic direct load control (DLC) algorithm will be executed which automates the curtailment process for the available flexible loads. In the present work, OpenDSS-Python co-simulation has been implemented with the aim to achieve the overload relief by changing the load curve of the distribution feeder. Implementation of DLC-Demand side management (DSM) technique reduces the supply-demand mismatch, decreases the line loss and aids in congestion management during peak load on the distribution feeder.**

Keywords— Direct load control, Distribution feeder, Flexible load, Monitoring, Peak load

I. Introduction

The conventional top-down design of electric power system consists of a transmission system transmitting power from large generating plants over long distances and a distribution system which distributes electricity to end-users. With higher supervision and control possibilities the monitoring of the transmission system has become more active in nature. However the control and monitoring of the distribution system is limited due to extensive complex and dynamic nature of connected loads. Power distribution is the weakest and the crucial segment in the power system[1]. This needs greater attention as this segment has a direct impact on utility's commercial viability and eventually on the consumers who pay for the service. The backbone for assured and quality electric supply is to implement an efficient and intelligent power distribution system.

In recent times with the worldwide growth in the economy, the demand for the energy is increasing. This impact can be seen in Indian scenario too. A decade ago India was one of the power deficit country[2]. Generation has increased in last two decades to keep up the growing economy and now India holds the position of third largest energy producer in the world. But the distribution system expansion and modernization is not in line with that of generation and transmission in Indian scenario[3]. Despite the enormous growth in energy production, the daily peak met for a given number of days is very low[4]. This fact clearly indicates that increased generation is not the complete solution to satisfy the increasing demand although it is a solution to fulfill the average demand needs. Constant and instant balancing of supply and demand is the need of the day to meet the increasing load demand. Integration of renewable generation is increasing in order to satisfy the increasing energy demand in an environmental friendly way. However, the contribution of renewable sources depend on the weather conditions leading to additional stress on the power balance of the system. Therefore the energy saving strategies rather than energy generation have become top priority in energy policies. Bureau of Energy Efficiency (BEE) and Ministry of Power (MoP) had introduced a number of programs during 11th five year plan for promotion of energy efficiency in India. Some of them are: energy conservation building code (ECBC) & energy efficiency in existing buildings, energy efficiency in small and medium enterprises (SMEs), agriculture & municipal DSM etc.[5]. With every unit of energy savings, the nation reduces its air pollutants, water use and associated land use.

The major problem that the electric utility is facing is the management of peak load demand[6]. Energy storage and DSM are the main tools to address the peak demand issues. Since the energy storage is an expensive solution, DSM is said to be the most promising tool to help in addressing the challenge of peak load demand management on the distribution network.

DSM is a tool which involves the consumers to achieve the desired load shape. DSM can be achieved in two ways: i.Energy Efficiency ii.Demand Response (DR) program. Energy efficiency can be achieved by purchasing energy efficient products and promoting high efficiency building practices. DR is to reduce the power consumption of the consumers from the utility end in order to balance supply and demand on the electric grid. DR can be achieved either by price based (Indirect load control) DR programs or incentive based (DLC) DR program. In Indian scenario, the price based programs such as time-of-use, peak pricing, dynamic pricing have not been implemented by the utilities on medium voltage consumers.

Deployment of appropriate DSM strategies are crucial in the developing countries[7], whereas in developed countries sophisticated technologies have already been implemented. At present the traditional methods available for control of distribution network are reconfiguration, adjusting on-load tap-changer, switching reactive power compensation etc., which are passive in nature[8]. Opening of the breakers of the

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feeders from substation during overload is one of the steps taken by the utility at feeder level, to bridge the gap between demand and supply. This results in blackouts in whole area of the feeder. Therefore to improve the services and health of distribution feeders, DSM techniques are necessary. DSM can be implemented either with or without smart technologies. DSM has been given less attention in developing countries due to lack of appropriate technology and capital costs. But there are DSM strategies that require minimum or no cost to implement and provide immediate results. These strategies results in energy conservation rather than energy generation[9].

To reduce the peak demand, flexible load control can be a highly valuable demand side resource. Demand resources have features like larger flexibility and fast response, unlike the expensive backup generators which are used during the system peak. This improves power system reliability, voltage profile and losses[10]. They can impact the load profile, reduce the peak load and reduce the energy usage[11]. For DLC-DSM, the utilities are more likely to prefer to go with larger loads as it calls for less investment in communication and possibly results in simpler billing procedures and performance verification. In this regard, large commercial Heating, Ventilation and Air-Conditioning (HVAC) system can be a potential, cost effective load in a power system[12],[13],[14]. By implementing DLC technique, the power consumption of HVAC system can be adjusted so as to follow intra hour load balancing[15]. Further, the initial investment can be reduced by using the existing building automation system for the new HVAC systems as well[16].

Despite the complication around the market structure, hardware and lack of experience, DR is the best source of flexibility in electric systems in Bangalore, India[17]. Based on willingness of consumers acceptance, the potential of DR flexibility can be maximized and successful implementation of DSM can be achieved. The energy conservation techniques become important for DSM, particularly in Indian scenario[18]. The energy conservation is a strategic approach for reducing the demand, as every unit of energy saved is equivalent to two units of energy generated. The reduction in energy usage due to large load response is considered as a Virtual power generation plant which can be used as Demand resource to reduce the system peak[19]. Such reduction is beneficial to the supplier as the role of the DR is a peak shaving to flatten the load profile and release the overloading conditions. DR also provides a reasonable solution to mitigate the fluctuations in the system, decrease the probability of load curtailment and decrease the electricity prices for consumers. Though the entire system may not be intelligent and smart, loads selected may be active and intelligent. By developing an automatic load curtailment algorithm for the available, flexible and intelligent loads, system peak can be reduced.

This paper aims at implementing DLC-DR technique to reduce the peak. An automated load curtailment algorithm is implemented for automatic demand coordination to reduce the system peak without consumer interaction. In intelligent distribution automation system there is interdependency between distribution grids, the communication networks and the associated control systems. This calls for a combination of tools which are capable of monitoring, controlling and analyzing the electrical system. Therefore in the proposed work, Python-OpenDSS co-simulation has been implemented to analyze the congestion occurring during overload.

II. METHODOLOGY

Following are the few assumptions considered for the proposed DLC-DSM:

i. The maximum allowable demand limit (P_{max}) in this work is assumed as 2500kW.

ii. IEEE13 node test feeder as shown in Fig.1 has been considered to carry out the work. The detailed description of the IEEE 13 node test feeder is provided in[20]. The node numbers included in the rectangular boxes are assumed to be offering a flexibility of 10% of their capacity. Frequency is assumed to be 50Hz in order to match the Indian power system. The spot load or the static load data of IEEE 13 node test feeder are tabulated in Table I. The IEEE13 active pattern is modelled utilizing the load pattern from a typical Indian urban load curve[21] for 24 hours sampled at 1 hour intervals.

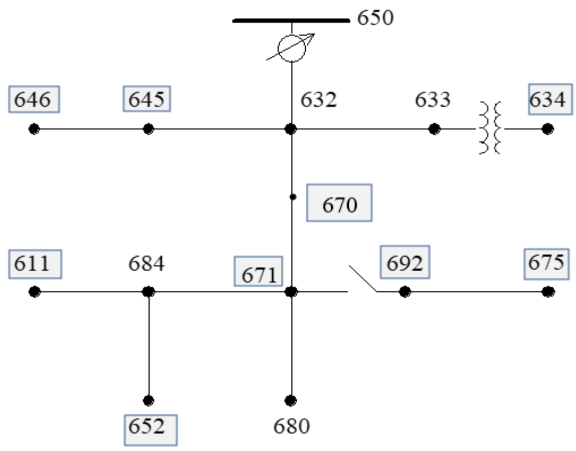

Fig. 1 IEEE 13 node test feeder

TABLE I. SPOT LOAD DETAILS OF IEEE 13 NODE TEST FEEDER

Node number	Ph-1	Ph-1	Ph-2	Ph-2	Ph-3	Ph-3
	kW	kVAr	kW	kVAr	kW	kVAr
634	160	110	120	90	120	90
645	0	0	170	125	0	0
646	0	0	230	132	0	0
652	128	86	0	0	0	0
671	385	220	385	220	385	220
675	485	190	68	60	290	212
692	0	0	0	0	170	151
611	0	0	0	0	170	80
670	17	10	66	38	117	68
	1175	616	1039	665	1252	821

The commercial buildings are responsible for a significant portion of the total energy consumption in any urban area. The work in this paper has been developed by keeping in mind the DR offered by thermal inertial of commercial buildings. It has been assumed that a group of buildings with centralized HVAC systems are under a predefined contract with the utility and are offering flexibility during the peak load condition. The distribution feeder nodes to which these buildings have been connected are considered as flexible load nodes. The flexible load nodes are 634, 645, 646, 652, 671, 675, 692, 611 and 670 (shown in Fig.1).

In a distribution feeder each load node has its own load profile and the aggregation of all those nodal load profile gives the feeder load shape. The distribution feeder congestion management mechanism due to overload should be in such a way that the maximum utilization of feeder assets must be ensured and at the same time the reliability of the system has to be maintained at an acceptable level.

In this work, Open Distribution System Simulator (OpenDSS)[22], an open source electrical power distribution system simulator developed by EPRI (Electric Power Research Institute) has been implemented. The distribution feeder is simulated to detect the congestions at sampling time step of 1 hour for a day (24 hours). In a possible congestion on the feeder, the total power consumption by the feeder can be identified by aggregating the power profiles of all the load nodes at that time interval considered. So the total load on the feeder, at the considered time interval can be given by :

$$P_{total} = \sum_{i=1}^{N} Pi \qquad (1)$$

Where P_i is the power consumption at each 'N' number of load nodes and P_{total} is the total load on the feeder. In case of congestion, P_{total} exceeds P_{max} and it is given by :

$$P_{total} > P_{max} \qquad (2)$$

In such an overload scenario, the control algorithm developed in Python takes action to curtail the loads available at flexible load nodes. In this work the number of flexible load nodes is considered as n=9. The amount of curtailment at the load nodes can be set by predefined contracts with the building consumers of that related load node. In this paper it has been assumed that all the flexible load nodes are offering a maximum flexibility of 10% of their capacity under predefined contract. Initially there will be a curtailment of 1% capacity at each flexible load node on indication of peak load. If $P_{i,j\ curtailed}$ is the value for 'n' number of flexible load nodes, the total amount of power curtailed in all those 'n' nodes will have to be equal to the amount of power exceeding the maximum allowable capacity. If not, the percentage curtailment will increase from 1% to 2% and so on till the maximum allowable curtailment i.e. m=10% in steps. The algorithm will continue curtailment operation for all flexible load nodes until the issue is resolved and system parameters are within acceptable limits. The $P_{i,j\ curtailed}$ is given by

$$\sum_{j=1}^{m} \sum_{i=1}^{n} P_{i,j\ curtailed} = (P_{total} - P_{max}) \qquad (3)$$

The flowchart for the proposed work is shown in Fig. 2. Python-OpenDSS co-simulations is carried out for 24 hours with a sampling time step of 1 hour. OpenDSS monitors the distribution feeder for overload condition. The monitoring of the feeder through OpenDSS assists in deciding on whether or not to carry out the DLC-DSM. Python is used to provide analytical capabilities to the OpenDSS software. Python does the analytics and control action needed to reduce the peak load on the distribution feeder. Once the monitors of the OpenDSS indicates the overload condition, the DLC-DSM algorithm written in Python will start curtailing the available loads under predefined contract which are connected at the flexible load nodes. The curtailments will be done in steps of 1% of the operating demand of the flexible load nodes. After each step of curtailment, Python will crosscheck the monitor of the Opendss for overload condition subside. If the overload condition persists then Python will increase the curtailment to 2% and so on till 10% of the operating demand.

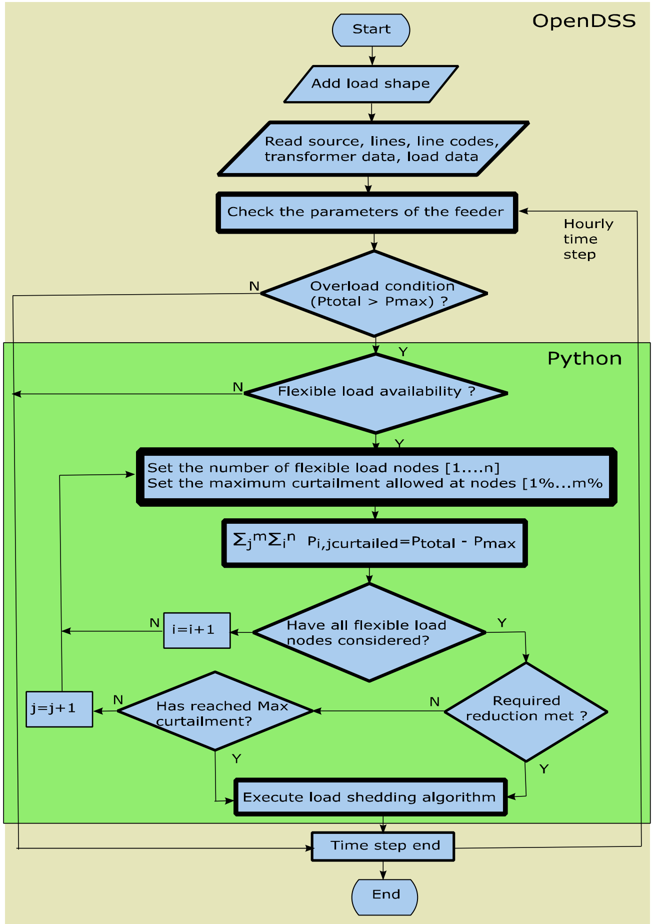

Fig. 2 Flowchart for the proposed work

Python drives the OpenDSS through COM interface and keeps on checking the distribution feeder condition on every hour by talking to OpenDSS. Once the OpenDSS gives the indication of overloading on the feeder, the Python subroutine executes load shedding algorithm to reduce the peak. This subroutine automatically iterates over lists of 'n' and 'm' to find the suitable curtailment transitions. The load type considered in OpenDSS simulation are of constant power loads. In OpenDSS they are termed as load type-1, which is constant power for both active as well as reactive demand. In this work, load type-1 has been chosen in order to investigate the amount of watt savings possible and hence can quantify the contribution of demand resource to the system during peak load condition.

III. RESULTS AND DISCUSSION

In an Indian urban feeder daily load pattern, typically there are two peaks termed as morning peak and evening peak (BMAZ_02-01-2021[20]). In this work, it has been assumed that one of the feeder under the urban zone carries the similar load pattern as that of the zonal load pattern and the same has been used to model the IEEE13 node test feeder. The dynamic load profiles of IEEE13 node test feeder thus obtained were provided as CSV files to OpenDSS software.

Whenever there is a peak on the feeder (In this case overload was on 9th, 10th, 11th, 18th and 19th hour) the Python runs load control algorithm and helps in relieving the congestion due to overload on the distribution feeder. The following cases are considered for analyzing the effect of DLC-DSM on feeder

Case 1: (Before DLC) With no DR: In this case, it is assumed that the loads are fixed.

Case 2: (After DLC) DR with DLC: In this case, flexible load nodes are offering a flexibility of 10% of their respective capacity.

The load curve before carrying out the DLC and after carrying out the DLC are depicted in Fig.3. The load curtailment occurs at peak hours. Since the load on the feeder is exceeding the set maximum allowable demand limit of 2500kW on hours 9, 10, 11, 18 and 19, the load curtailment is taking place in those hours without disturbing the loads for the rest of the time.

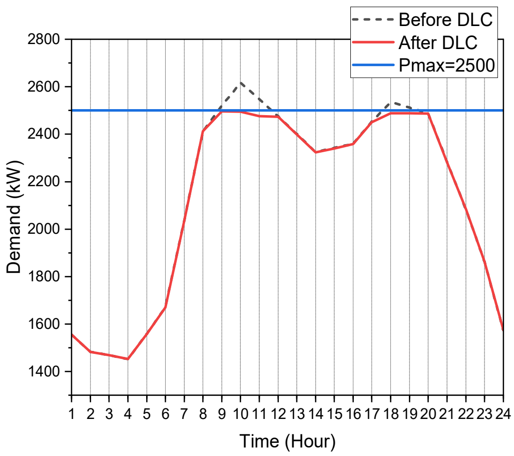

Fig. 3 Daily load curve with and without DLC

The curtailment taken at hour 9, 10, 11, 18, 19 are 23.16kW, 129.3kW, 70.90 kW, 47.18kW and 24.2 kW respectively. The load is curtailed from 1% to 10% on each flexible load node with steps of 1% till the congestion due to overload is relieved without violating the demand constraints. The changed load curve due to DLC-DSM on the feeder during the peak hours are more detailed in Fig. 4 by showing maximum allowable demand limit of 2500kW and the values of demand before and after DLC-DSM.

When loads actively participate in DLC-DSM to reduce the peak, the load shedding amount is greater and hence the depth of the DR is greater. The effect of different level of DR depth is depicted in Fig.5. Without DR or without load flexibility, the overloads can be seen on 9th, 10th, 11th, 18th and 19th hours. With availability of only 1% DR, one can mitigate the peak occurring on 9th and 19th hour. Similarly with the availability of 2% DR, one can mitigate the peak occurring on 18th hour and 11th hour. While 5% DR is required in order to reduce the peak on the 10th hour. Even though in the paper, it has been assumed that the flexible load nodes are offering a flexibility of 10% of their capacity, for the considered feeder daily load curve 5% load flexibility was sufficient to reduce the peak.

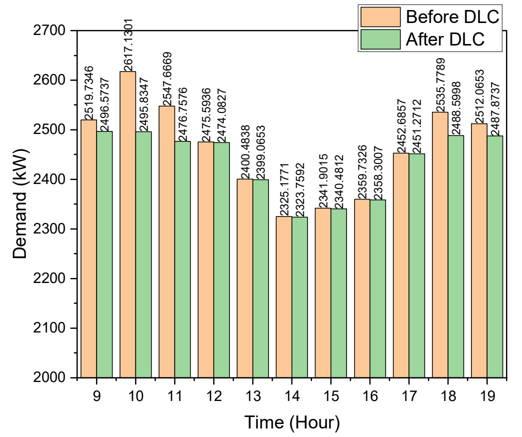

Fig. 4 Changed load curve during peak hours

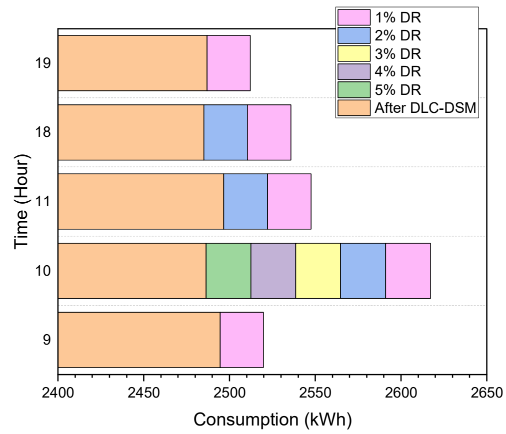

Fig. 5 Peak time feeder load with different demand response

The simulation for one complete day (24 hours) is summarized in the Table II. The energy consumption for the whole day before and after the DLC are 51019.14kWh, 17707.98kVArh and 50721.18kWh, 17483.69kVArh respectively. The daily feeder energy loss reduced from 51019.14kWh to 50721.18kWh. The feeder daily energy loss is reduced by 0.58%.

TABLE II. FEEDER SIMULATION SUMMARY FOR ONE COMPLETE DAY

	Before DLC	**After DLC**
kWh	51019.14	50721.18
kVArh	17707.98	17483.69
Peak kW	2617.13	2496.5737
Peak kVAr	2853.9168	2702.8085
Losses kWh	916.6949907	903.7933446
Losses kVArh	4558.375742	4489.862983
Peak Losses kW	57.43358793	51.71058388

The daily peak load of the feeder is reduced from 2617.13 kW to 2496.57kW by 120 kW which is about 4.6% reduction. Fig.6 shows the daily feeder losses with and without DLC. The daily peak power loss has been reduced from 57.43kW to 51.71kW corresponding to about 9.96% reduction. The total daily curtailment is 300kW. This implies that demand resource can be treated as virtual generation power plant contributing a total of 300kW, 225kVAr in a day to reduce the peak on the feeder.

A check for voltage issues during the 24 hours simulation was performed to verify the maximum and minimum voltage reaching at each sampling time. Fig. 7 shows the magnitude of the voltage measured at the feeder head for each sampling time step of 1 hour. The maximum p.u. voltage reached before and after DLC are 1.044361 and 1.044369 respectively. The minimum p.u. voltage reached before and after DLC are 0.979099 and 0.980771 respectively.

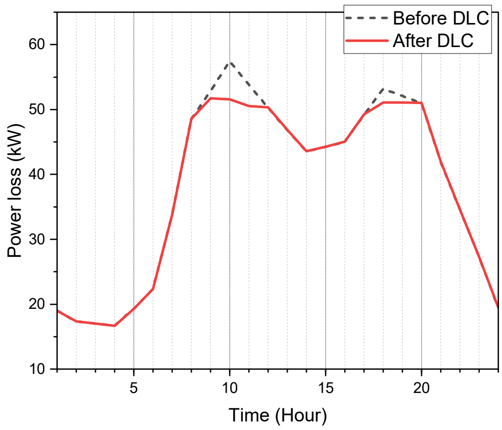

Fig.6 Daily feeder losses with and without DLC

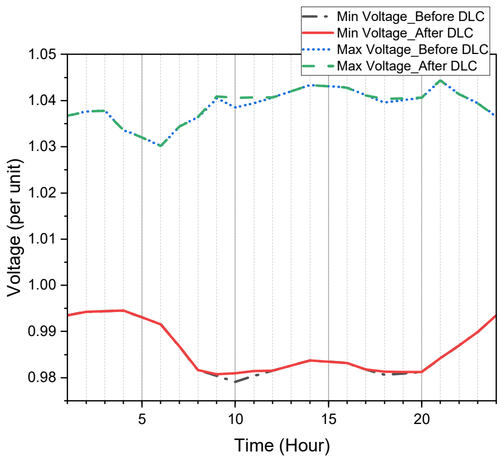

Fig. 7 Maximum and minimum voltages measured at the head of the feeder for one complete day

To further investigate the voltage issues, a check for voltages at all the neighboring nodes has been carried out at each sampling time step. Starting from source bus or the supply node, the voltage at each node is measured. All the node voltages were within the acceptable limits. To demonstrate the same, the 10th hour case has been considered in this paper, the time at which there is a maximum curtailment. Fig. 8 shows the voltage check for phase1(a), phase2(b) and phase3(c) at the feeder nodes during the 10th hour where there is a maximum of 5% DR.

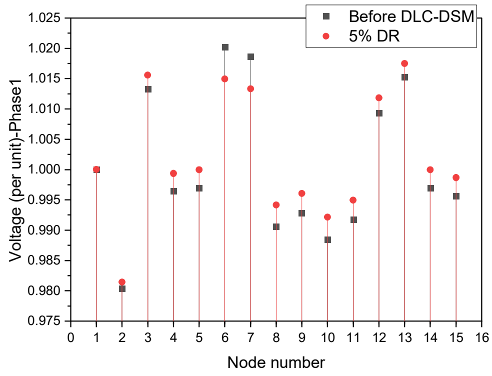

Fig.8(a)

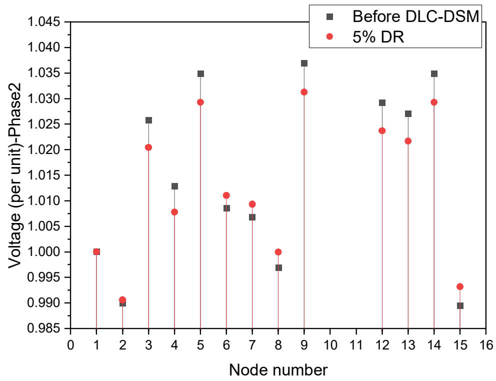

Fig.8(b)

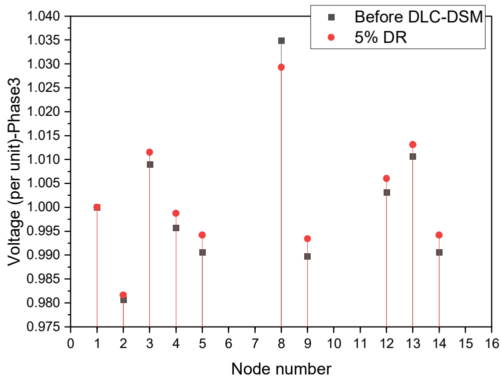

Fig. 8(c)

Fig. 8 Voltage check for phase1(a), phase2(b) and phase3(c) at feeder nodes during the maximum curtailment of 5% at 10th hour

Table III gives the details of the feeder node numbers which have been used in of Fig 8. Some of the nodes are with 3-phase loads while some with 2-phase loads (node no. 645, 646 and 684) and others with 1-phase loads (node no. 611 and 652).

TABLE III. FEEDER NODE NUMBERS

Sl No	1	2	3	4	5	6	7	8
Node No.	Source Bus	650	633	634	671	645	646	692
Sl No	9	10	11	12	13	14	15	
Node No	675	611	652	670	632	680	684	

When particular phase is not found, the phase-voltage measured at the node will be zero. For example node no. 645 is a 2-phase type, so phase-voltage can be found in Fig. 8(a) and 8(b) but missing in Fig. 8(c). The node no. 611 is of 1-phase type, so phase-voltage can be found in only Fig.8(a) and it is missing in Fig.8(b) and Fig.8(c). Voltage measured at all the feeder nodes in all the three phases during the maximum curtailment period are within the acceptable limit.

IV. Conclusion

In the present work, focus was to reduce the daily peak power to the extent possible. Unlike the earlier techniques used on DLC-DSM, which were difficult to replicate due to lack of standardization, the proposed work introduced a new framework involving co-simulation of OpenDSS and Python which is opensource and modular. DSM was applied through automated DLC which reduced the feeder daily energy loss by 0.58%, the daily peak by 4.6% and daily peak power loss to about 9.96%. The curtailment of 300kW, 225kVar obtained during the peak load period is treated as virtual generation power plant with its demand resource contributing to reduce the daily peak on the feeder.

The control algorithm developed in this paper showed significant reduction in daily peak power loss. However, this method limits the curtailment at the load nodes. For more detailed investigation, the control algorithm can be stretched to the individual loads taking into account the load behaviors and rebound effects. To achieve the smoother load control, sampling time can be decreased further and load curtailment can be done in smaller steps. The free simple framework proposed can be further modified, customized and enhanced using artificial intelligence techniques example : developing load models, load forecasting.

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