

Demand Response Model for Duck Curve on Pv Dominated System using Support Vector Machines Based Multistage Modelling

C.R.Sarin, Geetha Mani, S.Albert Alexander

Abstract: Solar Photovoltaic (PV) generation systems have a less Levelized cost of electricity (LCoE). As such, when solar energy is available, the demand response is scheduled in such a way that maximum utilization of solar energy is practised. But the power generation from a solar PV system is highly uncertain and unpredictable due to irregular solar irradiation. Also, the power generation is limited to a time fraction of a day. The impact of these negative traits in a power system is studied with the help of an analytical curve called “Duck curve”. “Solar Duck curve” is a graphical representation of time scaled imbalances between a SPV generation to peak demand. A steep or rugged part in a duck curve indicates sudden shortcoming of SPV generation with respect to the peak demand. Hence, during this period, the loads are shifted between solar PV sources and the main grid with respect to the insufficiency of solar power from peak demand. The proposed system is a machine learning-based multistage demand response system for meeting demand response of a SPV dominant duck curve. The model has four layers/stages. The primary layer is used to analyse the behaviour of the duck curve with the help of a Support Vector regression algorithm and the second layer is used for determining the operating parameters based on the economic constraints imposed. The third layer is a demand response model based on the previous layer, and the fourth layer is an adaptive signal-processing model used to improve the stability of the system. The obtained demand response model is updated continuously in an adaptive manner so as to improve the stability of the system. A hardware experimental setup is made with eighteen numbers of 24V/2kW interconnected solar PV real-time system which is used for validating and analysing the method.

Keywords: Demand response, Machine learning, Microgrid, Solar PV.

Nomenclature:

$P_{SPV, Peak}$ - Total Peak Power share of Solar PV systems

P_{MG} - Power share of Main grid

$P_{MG, Peak}$ - Peak power share of Main grid

P_L - Total load connected to Microgrid

$P_{L, Peak}$ - Total peak load connected to Microgrid

X_1 - Load share between the Main grid and Solar PV

Modules

P_{SPV}^n - Solar power generated on the n^{th} bus of the grid

$P_{SPV, Peak}^n$ - Peak Solar power generated on the n^{th} bus of grid

$P_{MG, Peak}^n$ - Peak power share contributed on the n^{th} bus of grid by Microgrid

$P_{L, Peak}^n$ - Peak load share on the n^{th} bus of grid

cf_{oc} - Cost function of the Operating cost

cf_{fc} - Cost function of the Fixed cost

cf_{tc} - Cost function of the Transmission cost

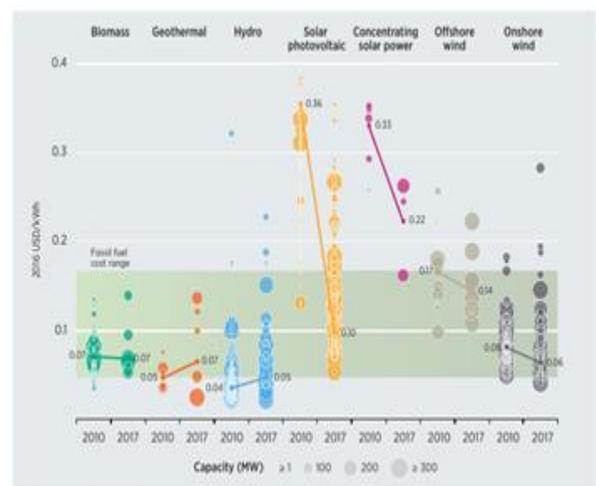
x - Load factor

afc - effective fixed cost factor

aoc - effective operating cost factor

I. INTRODUCTION

Swanson's law states that the price of a solar photovoltaic module tends to drop twenty percentages for every cumulative shipped volume [1][2]. As per International Renewable Energy Agency (IRENA) reports, the Global Levelized cost of electricity (GLCE) on utility-scale perspectives for renewable power generation technologies is shown in Fig 1. It could be noted that the GLCE of Solar PV generation system (SPVGS) has decreased up to 400% between 2010-17 [3][4]. As of now, solar PV systems are having the decidedly less Global Levelized cost of electricity (GLCE) compared to other renewable energy sources [5]. This has accelerated the installation of a very high number of solar systems for the electric power generation. In a grid, if a significant share of power is generated from the solar PV sources, such grids are labelled as solar PV dominant grids [6]. Economic constraints and robust demand response are two significant issues to be considered in the demand response of a solar PV dominant grid.



Source: IRENA Renewable Cost Database.

Fig1 : Comparison of GLCE of various Renewable energy sources (2010-17) Source : IRENA RE cost database

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1.1. Economic considerations on grid and user perspectives

The economic aspects of the demand response should be modelled by considering both user and grid aspects. In a grid-connected solar PV model, if a solar PV generation system is producing an excess of energy after meeting the local demand, the surplus power is fed back to the grid [7]. If a solar PV generation system (SPVGS) is unable to support local demand, additional power is obtained from the main grid. In all other circumstances, local SPVGS are disconnected from the main grid [8]. But the unit tariff from the grid side is determined by considering dynamic pricing as well as fixed cost [9] [10]. The fixed cost includes the installation cost and the depreciation whereas the dynamic pricing incorporates the operating costs.

The grid will be operating 24/7 which will cause a substantial operating cost [12]. However, the user will access the main grid if (and only if) the local SPVGS are inadequate of meeting the demand [13] [14]. In order to economize the grid, the total dynamic price as well as the fixed price for the entire 24/7 operation, should be collected from the user even though the user is utilizing the grid only for a short time span [15]. This has increased the tariff at grid level which caused accelerated installation of more solar PV systems as they have lower tariffs. This will generate an economic burden on the main grid. However, the role of the grid cannot be eliminated because the solar panels are capable of producing power only for a fraction of a day. Subsequently, the demand response is to be scheduled by considering the best economic options. The developed model makes use of machine learning methods in order to find the best economic models of demand response.

1.2. Robust demand response.

The power generation from a solar panel entirely depends on many parameters, such as solar energy irradiation, partial shading, panel soiling, the angle of inclination, etc. Most of these parameters are highly dynamic and hence the power developed from a solar PV system is highly fluctuating, disturbing, and convulsing. If the variations from SPVGS are beyond some limits, this will affect the stability of the power system [16]. If power generation from SPVGS is less than the load demand, the load should be shifted to the main grid. As the solar power generation increases, demand response will be shifted from the main grid to SPVGS and vice versa [17]. In both of the above cases, the power shift may be swift, rugged and accelerated. This will affect the stability of the system. The demand response should be modelled in such a way that it will not affect the stability of the system [18].

In a solar PV dominant system, most of the demand is fulfilled using SPVGS. This can be analysed with a graphical topology called "Duck curve". "Solar Duck curve" is a graphical representation of time scaled imbalances between a SPV generation to peak demand over the period of a day. The initial sections of the duck curve represent the shift of energization of the load from the main grid to SPVGS. While at the end of the curve, the actions are reversed. For some portions of the curve, the SPVGS are literally isolated from the grid. Some sections of the curve have abrupt or exponential changes. The switching the

power between the grid and SPVGS becomes more complicated in this area.

The developed system described in this paper is a demand response model focusing on the duck curve. The system has two objectives. The primary objective of the system is to determine the demand response model for a duck curve where the stability is taken as the primary criteria [19]. Instead of performing an instantaneous response, a gradual power shifting is performed. The secondary objective of the system is to regulate the demand response in the perspective of economic constraints [20]. The power-sharing is scheduled by incorporating both fixed and dynamic pricing [21]. Support vector machine is a machine learning method which is used as a mathematical model to predict the behaviour of a duck curve. Support vector regression classifies data into groups by creating an imaginary hyper plane between data points.

This paper has six sections. The primary section provides the technical analysis of grid-connected SPVGSs. It also analyses issues with demand response of grid-connected SPVGS. The second section explains the nature of the duck curve and the constraints for the demand response of a duck curve. The third part explains the experimental setup, hardware setup and methodologies used for the analysis. The fourth part focuses on the technical modelling and setting up constraints for demand response. The fifth part includes the algorithm of the developed model which has three sections. The primary section focus on the behavioural study of the duck curve and the second section provides a demand response estimation with economic constraints. The tertiary section is the signal conditioning part which will reschedule the demand response with respect to the stability constraints. The fourth section is the result and discussions.

II. EFFECT OF PV DOMINANCE

If the SPVGS are connected, for a load (PL), the power share of the main grid () is shown in equation 1 and Power share of the SPVGS () is shown in equation 2. The variable x is the sharing factor.

$$P_{MG} = x_i P_L \rightarrow 1$$
$$P_{SPV} = (x_i - 1) P_L \rightarrow 2$$

In a Solar PV dominant grid, a major share of the load is energized using SPVGS as expressed in equation 3.

$$P_{SPV} \geq P_{MG} \rightarrow 3$$

At any point in time, the primary criteria for the calculation are that the total power consumption should be at a minimum.

$$\text{Minimum } (P_{MG} + P_{SPV}) \approx \text{minimum}' 4$$

The total solar power PSPV can be found using equation 5 where P_n is the solar power generated on the nth bus of grid

$$P_{SPV} = \sum_{n=0}^{\infty} P_{SPV}^n \rightarrow 5$$

Solar power generation is highly volatile. Suppose the solar power used for energizing about 40 percentage of the demand. If the sky suddenly becomes cloudy, the power generation thus decreases to zero. This may happen even

within a fraction of second. This will create a situation so that there is a need of sudden power shift from SPVGS to the main grid. If the rate of the change of power is higher than the threshold level, this may affect the stability of the grid. The threshold limit depends on the operational and technical parameters of the grid. Initial limits are found using Support vector regression of all available limit levels obtained on each iteration from n to

$$\frac{\partial(P_{MG,SPV} - P_{MG})}{\partial P_L} \geq limits \rightarrow 6$$

There are some individual cases in a solar PV dominant grid whereby similar situations may occur. The availability of solar light may vary from time to time, as shown in Fig 2. This will not have a linear change from morning to evening. Some part of the duck curve has a sudden or steep change which may cause an undesired rate of change of power. The situation may worsen if the grid is solar PV dominant. Such changes are most undesirable when the grid is operated in the off-grid model. The behaviour of a duck curve is discussed in the next section.

III. ANALYSIS AND EFFECT OF DUCK CURVE

In most of the cases, solar power generation will be maximum at midday but minimum at sunset and sunrise and zero at night. The variation of solar power generation from sunrise to sunset is not uniform throughout the curve. At some part of the curve, it is linear, at another part, it is parabolic, and at another part, it is even exponential. As the system goes through the changes in the curve, power should be shifted between SPVGS and the main grid. A sample duck curve is shown in Fig 2.

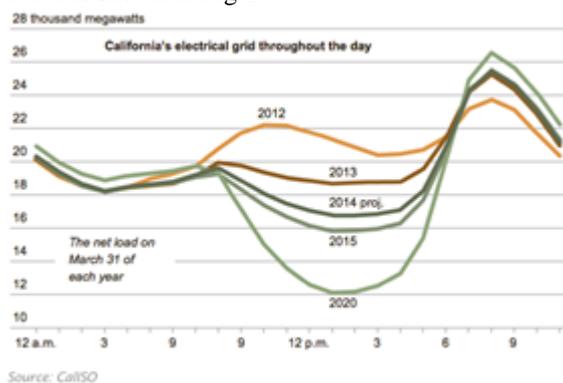


Fig 2: Duck curve

The analysis of a graphical representation of a duck curve can be performed as explained below. For ease of analysis, the "duck curve" is split into seven different sections.

1. Section A: From sunrise to the late sunrise, for a short period, the curve has a parabolic nature.
2. Section B: The subsequent section has a slow increase in power generation. The first two sections will be contributing towards about 25 to 35 percent of the curve.
3. Section C: The third section shows the solar generation curve for late morning and early midday, which will create a parabolic increase in power generation.
4. Section D: The fourth section showcases the power shift between the midday to an early evening where the power generation will reach its peak. During this section, the power generation is almost constant.

5. Section E: As the early evening starts, solar power begins to decline. There will be an exponential decline in power generation. This will create the fifth section.

6. Section F: The exponential curve and sometimes continuous up to zero power generation. There will be a limited amount of power generation until the sunlight becomes zero. This part is taken as section F

7. Section G: During this period, the solar PV systems contribute decidedly less or zero power to the grid

As the Solar PV generation increases, the main grid will switch off their sources or reduce the power available to the Microgrid and vice versa. During sections A and B, the power is gradually shifted to the SPVGS. Hence the SPVGS contributions will increase gradually. The demand will be met with contribution from both Maingrid as well as SPVGS.

Section C has a parabolic nature but for a span of more extended period. During this period, the power is gradually shifted to SPVGS, but in an accelerated model. By the end of section C, the solar power generation is at its peak. Hence the peak load will be probably met with SPVGS along.

During the Section G, the Solar PV modules are isolated from the main grid, and the load will be shifted entirely from Solar PV modules to other sources. At this stage, SPVGS will be capable of meeting Peak load or more.

The main issue arises during Section C and E where there is a rapid change in the solar power generation. During this period, there will be fall in SPV generation because of which the rate of change of power may exceed the permissible limit. The effect is more in section E. If there are no sufficient sources available to meet the load, the system may undergo overloading. Sufficient pre-addition of sources is required so as to avoid overloading.

There are many methods for demand responses in a Microgrid. Normal methods are less favoured to be used for the demand response of a Duck curve. This is because the conventional methods are more equipped with circumscribed or restricted changes in the demand unless it is a fault. But some part of the duck curve is having steep changes which may be misguided as faults.

IV. EXPERIMENTAL SETUP AND HARDWARE MODEL

The analysis is performed with an experimental Microgrid model. The sample Microgrid model is a coalition of 18 buses as shown in Fig 3. A 2kW, 24V DC solar PV generation system is connected to each bus. For the experimental setup, a random sample load is connected to each bus, and the load is varied from 0 to 150% of the maximum capacity of the bus. A resistive load is used for experimenting. The main grid is connected to the Microgrid through a central axis grid. A smart meter made of Atmega328P is connected to each bus in order to measure the present load connected to the bus, the solar power developed at the bus, and the power delivered from the grid [22] [23]. The smart meter is developed using an AVR



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microcontroller connected to a current source and voltage source. These parameters are measured every 100 microseconds, and this data is sent to the central server via Wi-Fi. The data from the various smart meters is collected at a central data acquisition system which is developed using a single board computer. A MySQL DB is used to store the data in a central Single board computer server. Once the data is obtained, the mathematical modelling is performed using the python scripting language. For ease of analysis,

24-hour data is used for processing. Research methodology adopted in this paper is experimental modelling, primary and secondary data analysis, quantitative and qualitative validation and applied remodelling. The output of the system is verified with standards including IEEE 1547, IEEE 937, IEEE 1526, IEEE 2030 etc. System is remodelled again and again until the standards are achieved.

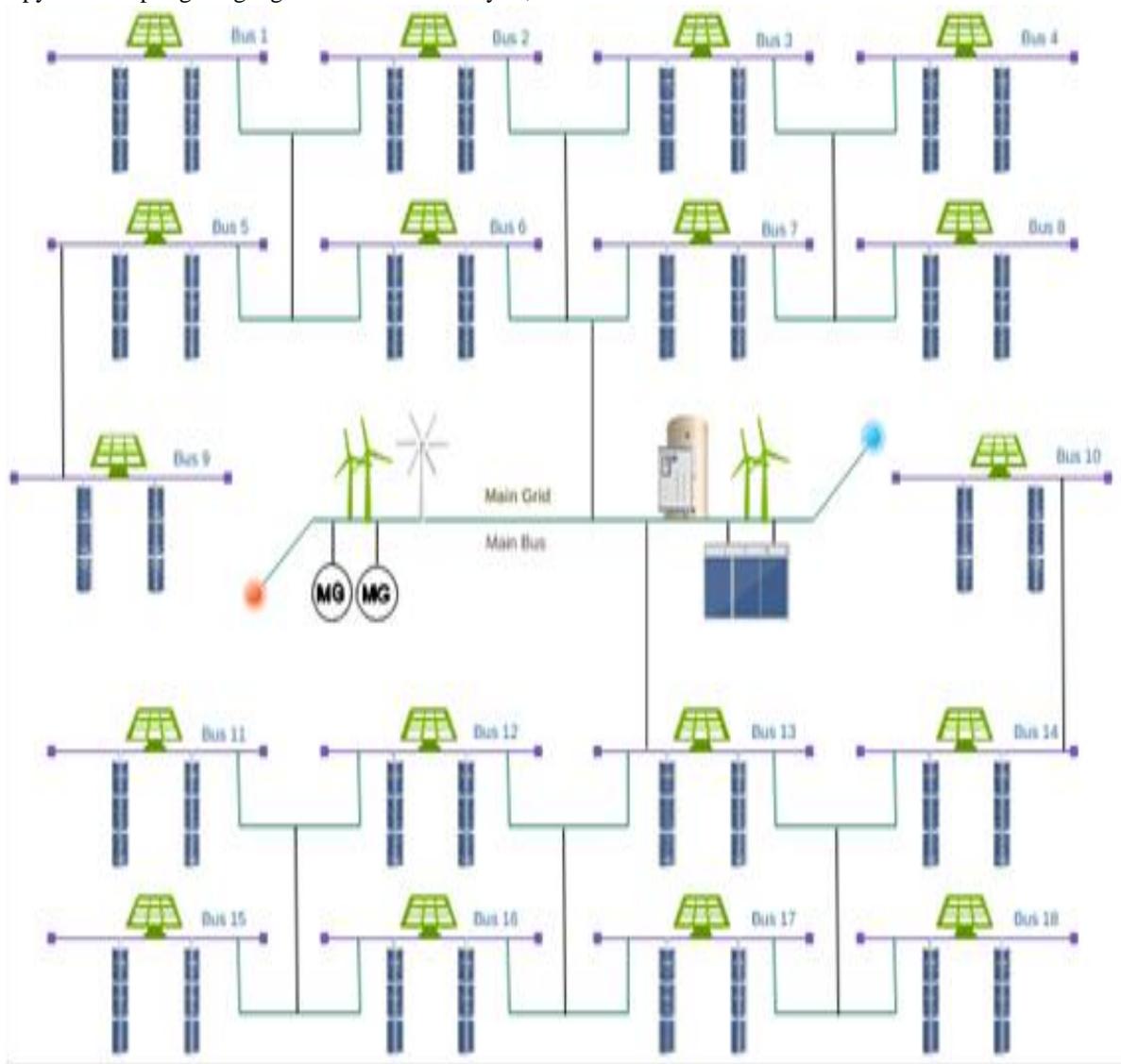


Fig3: Experimental 18 Bus Grid connected Solar model

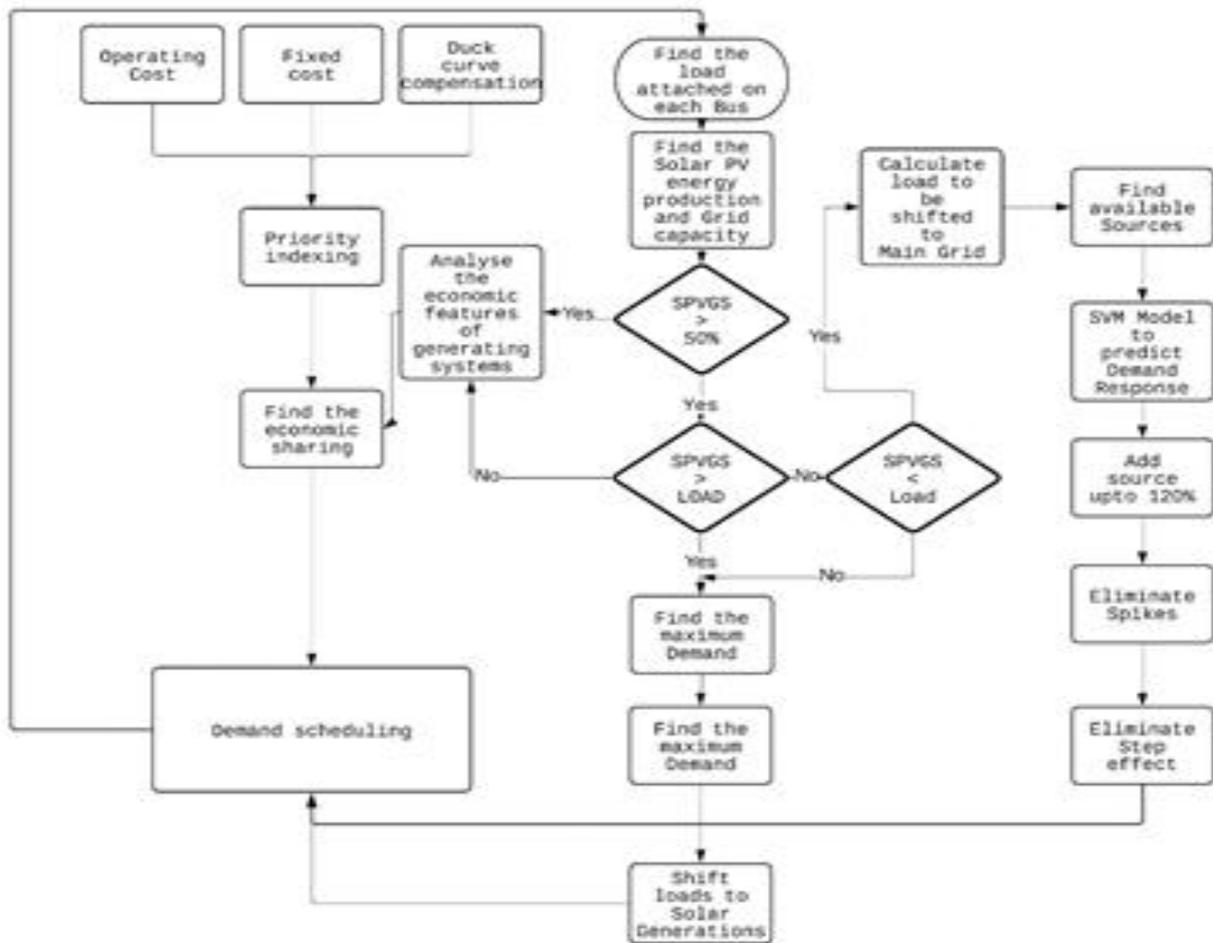


Fig 4: Flow chart of mathematical modelling

V. MATHEMATICAL MODELLING OF THE SYSTEM

The base model of economic and mathematical modelling of the system is shown in Fig 4. The operations performed in Fig 4 are discussed in Section 6.

This system has three sections.

5.1. Behaviour analysis of load and solar curve

The primary section of the "modelling" is used for the study of the load and source. At first, the measurements such as the solar power developed in SPVGS, instantaneous load, and the power delivered from the main grid are analysed. The parameters for analysis include the rate of change of load, rate of change of solar power, rate of change of power delivered from the grid, the peak solar power, maximum and minimum load, the maximum and minimum power generation capacity, the amount of power developed in each bus, and the overloading and underloading conditions. From the values measured, operating constraints are decided.

5.1.1. Maximum load and minimum load

Any condition, maximum available power at any bus is set to 120% of the maximum load. The additional 20 percentages are added in order to avoid the overloading due to sudden changes in solar power generation or due to any

other faults. Minimum load is measured in order to find the minimum installation capacity.

5.1.2. Rate of change of power

The stability of the grid has much dependence on the rate of change of power. The rate of change of load, instantaneous solar power generation and main grid contributions are all measured. At any point in time, the rate of change of solar power generation should be proportional to the rate of change of power contribute from the main grid as shown in equation 7. This will help to provide a stable demand response so that a proper power shift is carried out between SPVGS and the main grid. The rate of change of total power available should be less than the rate of change of load as in equation 8.

$$\frac{\partial(P_{SPV})}{\partial P_L} = -\frac{\partial(P_{MG})}{\partial P_L} \rightarrow 7$$

$$\frac{\partial(P_{SPV} + P_{MG})}{\partial P_L} = -\frac{\partial(P_L)}{\partial P} \rightarrow 8$$

5.1.3. Peak Power capacity of Solar and Grid

The load demand response should be designed in such a way that the sum of peak generation of SPVGS and the main grid should be higher than that of the maximum load as shown in equation 9. The load factor x is taken up to 1.2 times (120%) that of the peak load. An additional 20% of the load is taken for security constraints.

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$$P_{MG,Peak} + P_{SPV,Peak} > x * P_{L,Peak} \rightarrow 9$$

VI. DEMAND RESPONSE AND ECONOMIC MODELLING

The analytical modelling of the system is as shown below
 Layer 1: Identify the Power-sharing constraints as described in section 5

Layer 1 Step 1: Determine the current/instantaneous Load, Solar PV capacity, and Grid power capacity

Layer 1 Step 2: Determine the cost function/unit price of sources as shown in equation 10 and 11. Priority is given to Solar power, and the value of x is set to "2" as a initial reference. It should be noted that the high priority is given to operating cost by adding square of the load factor. By changing the value of x, the cost equations can be changed at any time.

$$aoc = x^2 \{ cf_{oc} \varepsilon P_{SPV}, P_{MG} \} + x \{ cf_{LC} \varepsilon P_{SPV}, P_{MG} \} \rightarrow 10$$

$$afc = x \{ cf_{fc} \varepsilon P_{SPV}, P_{MG} \} \rightarrow 11$$

Layer 2 Step 1: Find the grid behaviour using Support Vector Regression. This has two steps

Find the load/power behaviour with respect to the equation for five consecutive days. For the verification of the results, find the cumulative behaviour of load/power curves for five consecutive days, which is taken using Support vector regression. The plane of interception of Support vector regression is set in such a way that maximum demand response falls under SPVGS based response.

The new load/power function $f(P_{SPV, MG, L})$

$$f(P_{SPV, MG, L}) = f(P_{SPV, MG, L} \omega) + b \rightarrow 12$$

$\omega \in X, b \in R$

$f(P_{SPV, MG, L})$ is the regressive function with respect to the variable w and constraints of the w is set in such a way that

minimum of $|1/\omega^2|$

So that

$$f(P_{SPV, MG, L}) - f(P_{SPV, MG, L}, \omega) - b \leq \varepsilon \rightarrow 13$$

$$-f(P_{SPV, MG, L}) + f(P_{SPV, MG, L}, \omega) + b \leq \varepsilon \rightarrow 14$$

From the cumulative behaviour obtained, features such as maximum and minimum load/power, load/power at each bus, the rate of change of the load/power etc. are found first. This is then applied to equations 1-9 in order to set up technical constraints and criteria.

b. Once the technical parameters have been found, a possible combination of load, SPVG and MG power is found. The maximum load/power is set by analysing the highest of the load/power curves and operating load/power is set based on the cumulative load curve. Still, the values are variable in any condition whenever it is necessary.

Layer 2 Step 2: The equation 10A and 10B will provide the operating and transmission cost of the total system. At any time, the total cost function is set to be as minimal as possible. To identify the optimum value, the following procedures are performed.

A power share between SPVGS and the Microgrid is found

The source with the maximum share is identified

It is assured that SPVGS with maximum power sharing capability have the minimum cost function

Else reverse the values.

$$|afc * (\text{minimum}(PSPV, PMG)) + (1 - afc) * (\text{maximum}(PSPV, PMG))| \cdot \min \quad (15)$$

$$|aoc * (\text{minimum}(PSPV, PMG)) + (1 - aoc) * (\text{maximum}(PSPV, PMG))| \cdot \min \quad (16)$$

Layer 2 Step 3: From the equation 14 and 15, the economic constraints, demand response is rescheduled by considering constraints from equation 1 to 9.

Layer 3 Step 1: Applying Support vector regression again on the final curve of five consecutive days, the cumulative effect of the duck curve-based demand response with respect to economic constraints also found. From the cumulative curve obtained, the very next demand response ranges for each SPVGS as well as Main grid can be predicted.

Layer 3 Step 2: Using the predicted data, economic and technical constraints are remodelled.

Layer 4 Step 1: If the load scheduling curve has abrupt or exponential change, the demand response model is rescheduled with a stepwise change of the power shift. The stepwise demand response functions as kept as minimum as possible. If the small stepwise source is not available on the grid side, demand response is met with SPVGS.

Layer 4 Step 2: If the rate of change of demand response curve has spikes, apply spike filter which include avoiding fluctuation sources. This is done by a step shift of power on this area by meeting the peak value of the spike.

Layer 4 Step 3: An adaptive feedback is implemented for modifying demand response with respect to new stability constraints.

VII. SIMULATION RESULTS AND DISCUSSIONS

The objective of this section is to analyse the developed model. The developed machine learning model is implemented in the hardware model and the results are plotted from the main server model. The results will provide an overview of the effectiveness of the system. Fig 5(a-f) shows the graph which showcases the power supplied from Main grid with respect to a time span of 24 hours for 18 different buses for 6 consecutive days. Each bus will have a different level of Solar power generation, as well as load behaviour. This Fig shows the non-uniformities and uncertainties in the power generation. Also, the demand from each bus point may vary from time to time. As shown in the curve, with some buses, the SPVGS contribution shows very high power whereas for some buses it shows zero or minimal contribution. The buses are thus behaving differently on different days. Some curves have smooth variations whereas some curves are highly fluctuating. Some curves do not have Section A-G completely. Due to the effect of Solar PV dominance, the curves with all the sections will have prominence. All these curves show the power generation/sharing behaviour of a solar PV dominant system is highly uncertain and unpredictable. A static

control model cannot meet the requirement of such a dynamic system.

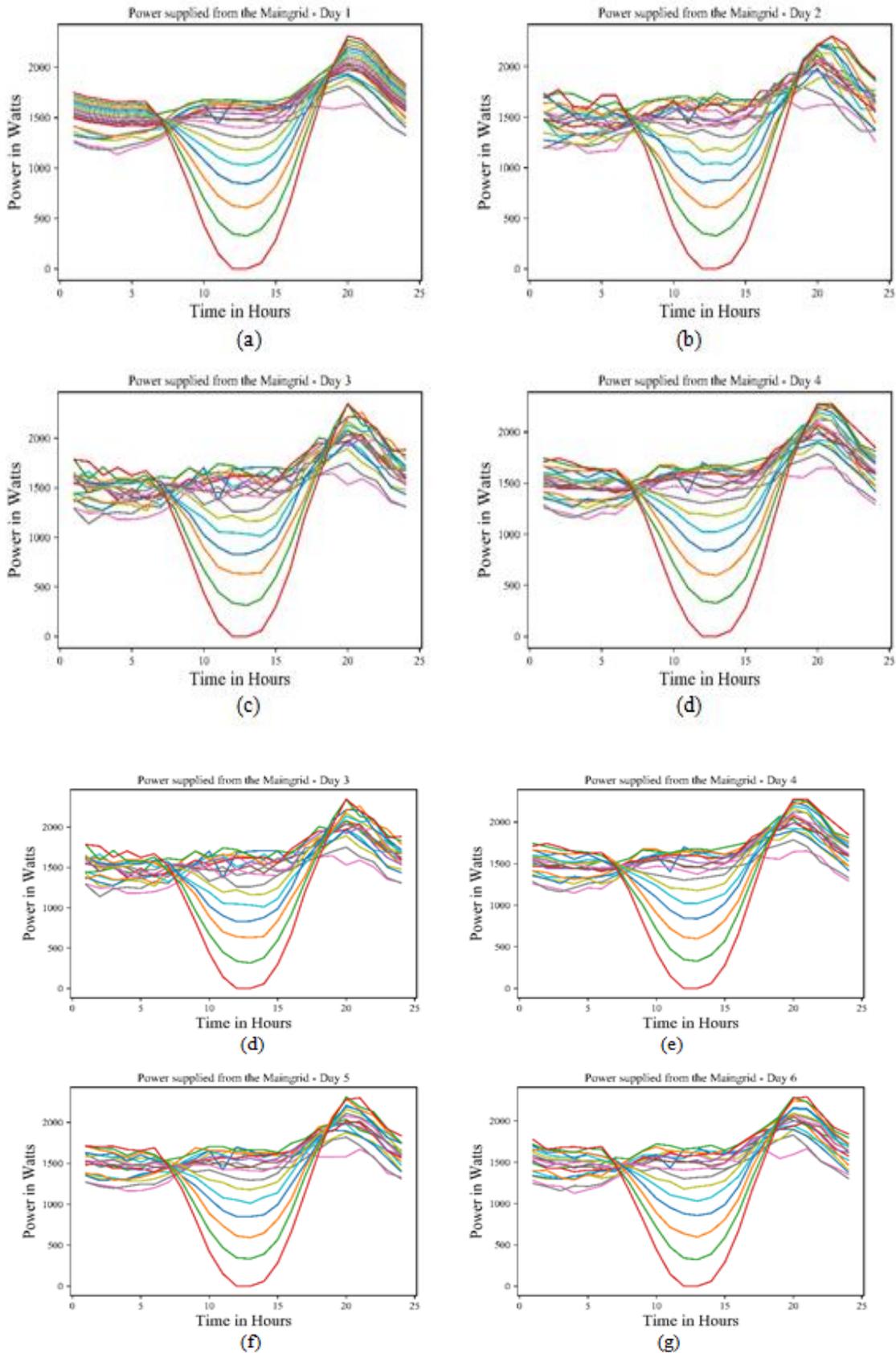


Fig5: Sample Duck curves for six consecutive days

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The cumulative or effective load by considering all the loads on different busses is found using a Support Vector Regression. Despite the average load, the cumulative effect is a regressive effect of all the loads. Fig 6 shows the cumulative effect of the loads for 3 consecutive days. This curve provides an effective behaviour of the load which will be useful in deciding the limits of power sharing. Using the demand response could be as explained in the demand response model.

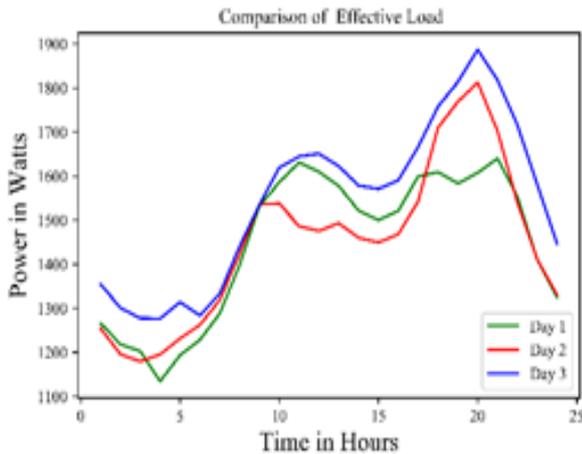


Fig6: Cumulative load distribution for three days

Fig 7 shows the cumulative contribution from the Grid to the entire 18 buses for 24 hours. In Fig 5, during Solar PV dominance, only a few curves demonstrate zero or fewer contributions on the buses. Still, the effective or cumulative curve shows that PV dominance has a considerable impact which may reduce grid contribution down to zero. Thus, this data basically provides the impact of SPGVs in the grid.

This data is helpful in scheduling the demands with respect to the change in SPGV generation.

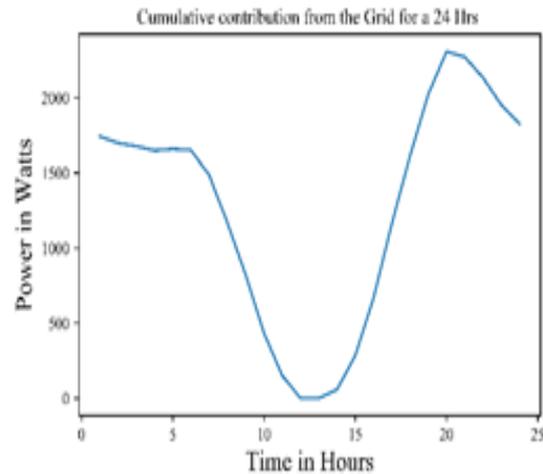
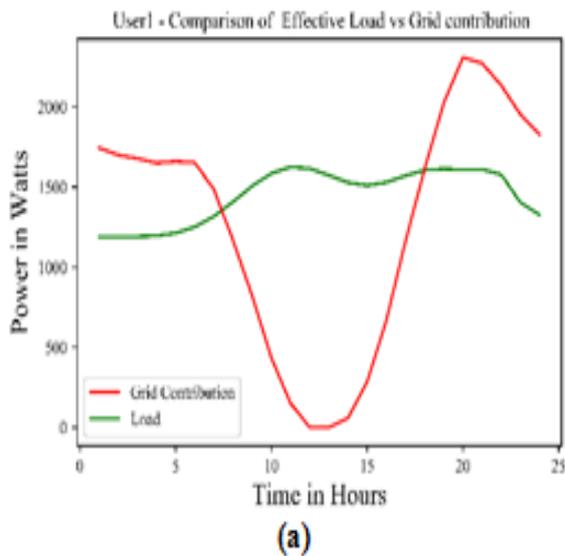
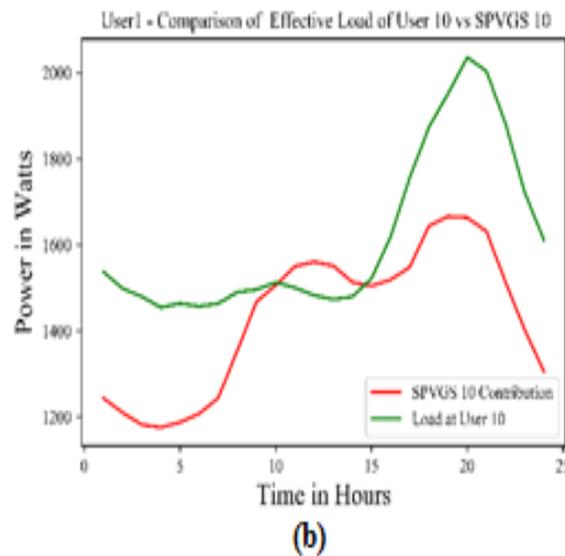


Fig7: Cumulative Grid contributions towards the available load

Fig 8a shows the deviation of cumulative grid contribution with respect to cumulative load changes. This data helps to identify additional power required or overloading. During the initial and final stages, Microgrid contribution is made higher than the load. During solar PV dominance, the grid level contributions are less than the load. The difference is that the curve has two parts. The total power is usually kept at 120% of the total load. The other differences are met via additional sources such as SPVGS. Fig 8b shows the load from User 10 with respect to contributions from SPVGS connected to SPVGS of User 10. Such data will provide information on the behaviour of a user load with respect to SPVGS generation.



(a)



(b)

Fig 8: Cumulative Grid contribution vs Load

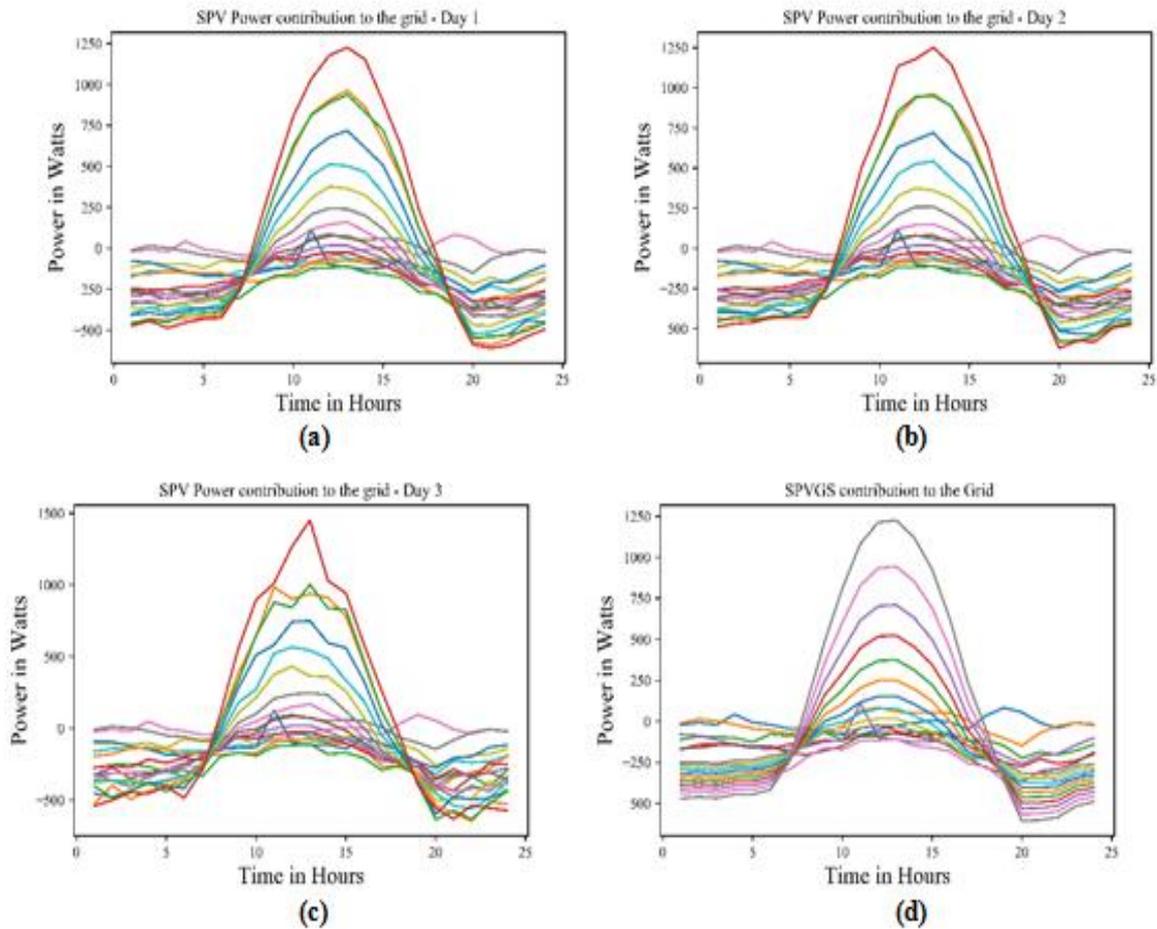


Fig9: Solar power generated for four consecutive days

Fig 9(a-c) shows the output of SPVGS for four consecutive days for 18 buses for a period of 24 Hrs. The power generation at the same buses can be at different on different days. It should be noted that the negative power generation shows that on such occasions, the power is delivered from the main grid. This is added to showcase the possible effect of uncertainty in Solar PV generation. This curve helps to calculate the power sharing between grid and SPVGS.

Up to this part, the analysis has focused on identifying the behaviour of grid, load and generation systems. The behaviour of the load, SPVGS and power contribution of the Microgrid have been identified. Using this data, the first and second layer of the demand response is modelled. As per the modelling, once the solar PV systems can meet the demand, the power is shifted from the grid to the SPVGS instantly. The variations of the grid power contributions are shown in Fig 10. This will provide information on the parameters such as rate of change of power shift, maximum and minimum load requirement, load scheduling plans, load shedding plans, possible chances of overloading.

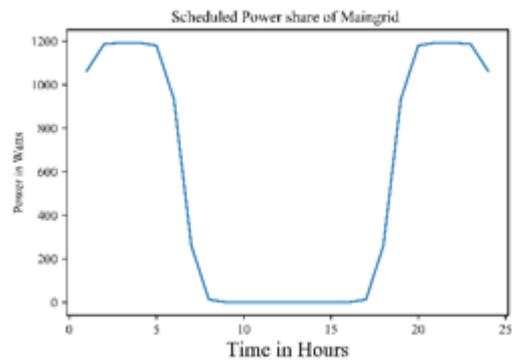


Fig 10: Grid Power contribution on direct loading

Up to this point, the paper has studied behaviour of the system including various operating and technical characteristics. Now the paper will analyse the issues with the demand response model developed and their remedies.

There are two concerns with the above model.

1. The power shift from the Maingrid and SPVGS models are instantly performed. This may affect the stability of the grid as the rate of change of power shift is very high.
2. The Section A-D of the Duck curve does not have a linear or stepwise behaviour. Yet, grid power is shifted instantly. This will cause additional accumulation of unused sources, which may cause power loss.

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Due to the above problems, the stepwise shifting of power is preferred over sudden change. Fig 11(a) shows the special scheduling required to deliver the power. Instead of providing an instantaneous shift of power, it is performed in a step-by-step manner. From time to time, the sources are gradually added. This method will reduce the disturbances in the grid during integration/disintegration of the sources.

Still, it has a steep change during Section C which should be avoided. This is performed at control layer 3 as discussed in section 6. As a result, the model is rescheduled based on the current status by further stepwise load scheduling. Fig 11(b) shows the splitting up of section C in steps. This will reduce the transient surges in the system and improve the stability of the system.

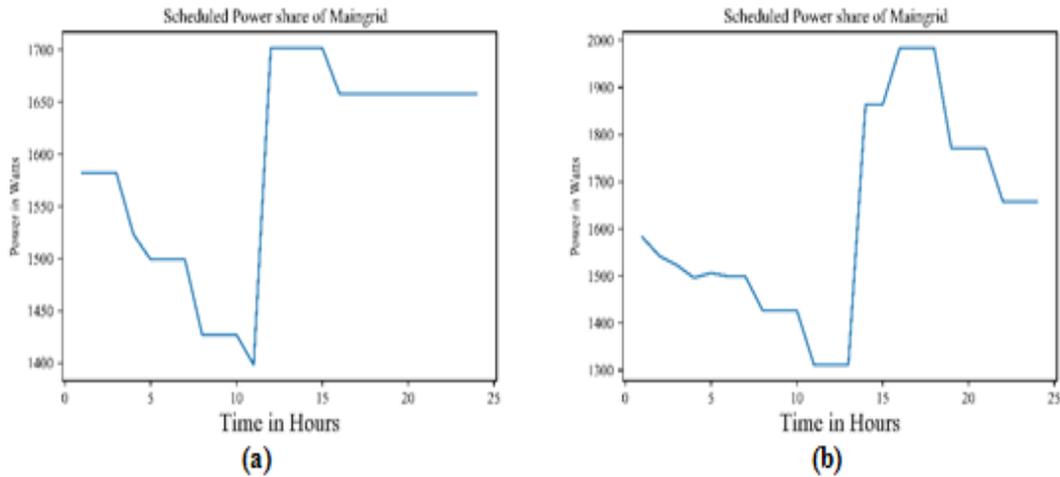


Fig 11: Grid Power contribution with step loading

This will cause additional accumulation of the sources and create energy losses. This is eliminated by modifying the model and adding small stepwise scheduling. Multiple additions of the stepwise scheduling cause the creation of

power spikes as shown in Fig 12(a). The model is again modified by applying spike filtering as shown in Fig 12(b). Still, the resolution of the step sources is limited to the minimum level of power sources and economic constraints.

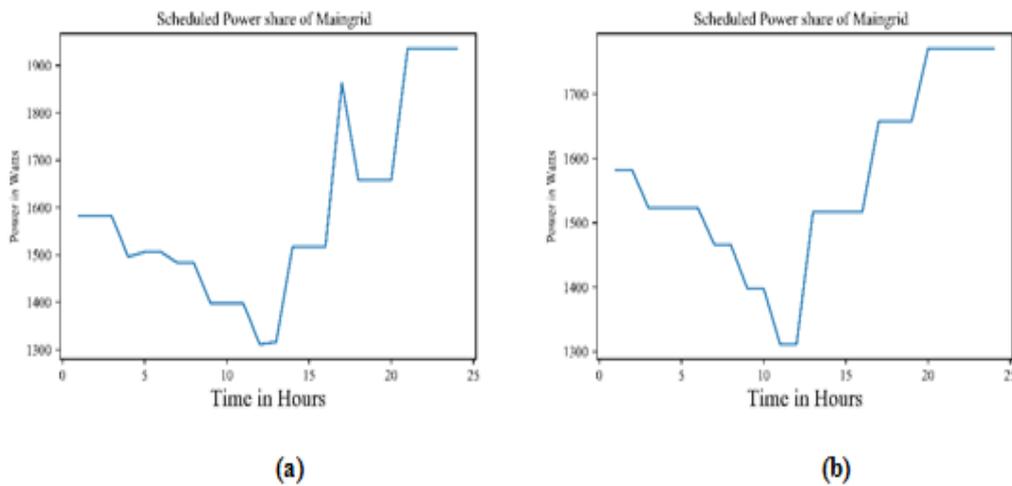


Fig12: Grid Power contribution with filters

A bandpass filter methodology is implemented for the removal of the spikes. The signal processing methodology is modified to fit with the present model. The spike filtering will remove the transient surges and smoothen the transition of power from the grid to SPGS and viscera. This may again remove the small step additions which will again create abrupt change as shown in Fig 12(b). This is avoided

by continuously repeating the same procedure. As a result, this is an adaptive model. Finally, a smooth demand response model with a minimum rate of change of power is obtained as shown in Fig 13(a-b).

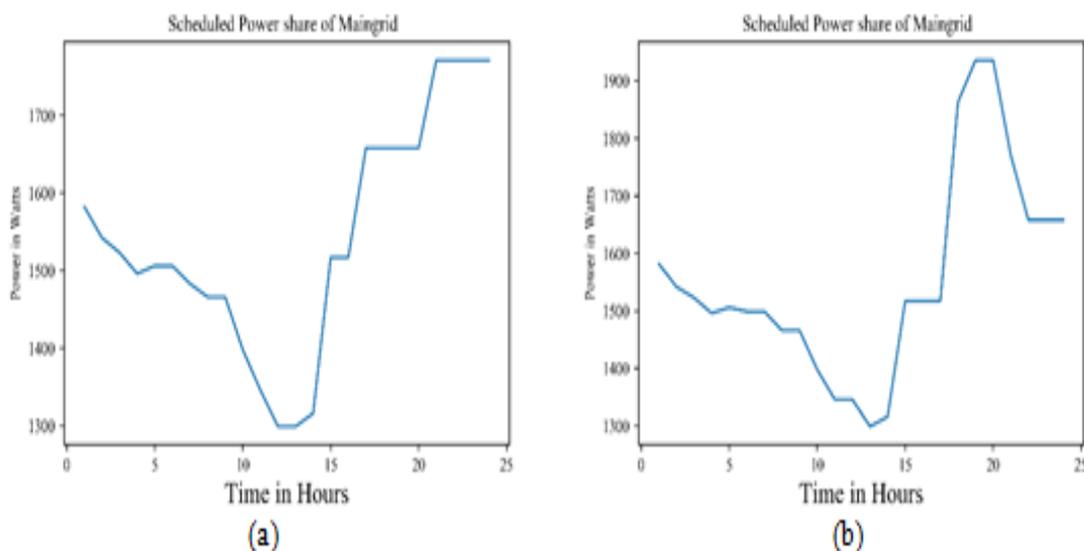


Fig13: Adaptive Grid Power contributions

Hence, even though an SPVGS is producing power, it is not compulsory to attach it to the system. This is practised so as to provide stability during a power shift. Fig 14 shows the probability of integrating an SPVGS over a period of 24 Hrs, for 18 different SPVGSs. Predicting the probability in advance using the below curve helps to prepare and integrate a source without any time delays being necessary.

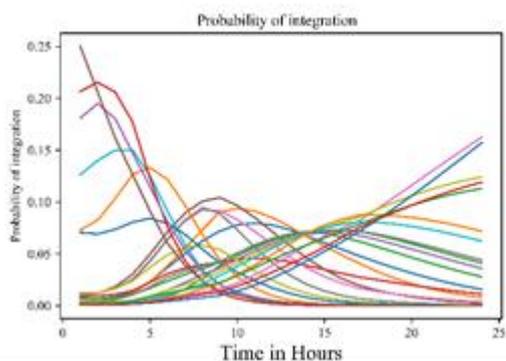


Fig 14. Probability of Integration of several SPVGS

VIII. CONCLUSION

The demand response with respect to the duck curve is one of the significant issues in a Solar PV dominant grid. This is a complex task, as both economic and technical constraints should be satisfied for optimal scheduling and ensure the stability of the power system. Eighteen 24V, 2KW interconnected solar PV hardware model is used for implementing the proposed methodology and the required analysis is done. The developed system analysed the behaviour of a duck curve using a multi-layer SVR model. The economic and techno-operating constraints are identified by the obtained model behaviours. The demand response is scheduled using both technical and economic constraints imposed. The demand response model is updated using an adaptive methodology to obtain the best-fit result as per IEEE standards discussed above. The rapid and steep change in demand response during scheduling is modified to gradual and smooth variations. The required numbers of optimal sources are predicted using SVR. The proposed model is focussed on source side demand response. The

same proposed technique will be extended to highly uncertain and fluctuating load conditions are proposed as a future work.

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