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Review of PV Power Ramp Rate Control Methods and Their Requirements

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Abstract- Grid codes play significant role in elaborating power system characteristics, such as limiting ramp rate of different kinds of power plants. Using new generation of energy sources, like solar energy develops the necessity for controlling the characteristics of these sources such as their power ramp rates. While solar power is going to increase or decrease, ramp rate control must be applied. There have been suggested different strategies for power ramp rate control. Some of these strategies need batteries and some do not. Due to solar radiation uncertainties, using energy storage systems for controlling power ramp rate looks inevitable. On the other hand, batteries add huge costs and unreliability to the power systems. As a result, there is a tradeoff among initial cost, reliability, security, and operation costs for selecting optimal strategy for photovoltaic power ramp rate control in a system. Also the acceptable error margin of grid is a decisive factor. In this paper schemes of some power ramp rate control are discussed. In addition, advantages and disadvantages of different types of schemes have been analyzed. Also, in this literature different types of power ramp rate control strategies for photovoltaics have been clustered into some major sets. Besides, power ramp rate control is essential for novel schemes such as virtual synchronous machine, so emerging virtual inertia in novel power grids is another motivation to establish improved methods for controlling power ramp rate control of renewable energy sources. Thus, in this paper there is a section discussing about the applications of power ramp rate control schemes.

Keywords: Battery Energy Storage System (BESS); Grid Code; Photovoltaic Power Plant (PVPP); Power Ramp Rate Control (PRRC); Solar Energy.

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Abbreviations

BESS	Battery Energy Storage System
CCGT	Closed Cycle Gas Turbine
CES	Conventional Exponential Smoothing
CSI	Current Source Inverters
C-PCS	Control and Power Conditioning Systems
EDLC	Electric Double Layer Capacitor
EMA	Exponential Moving Average
FSM	Frequency Sensitive Mode
HECO	Hawaiian Electric Company
HESS	Hybrid Energy Storage System
LPF	Low Pass Filter
MA	Moving Average
MAP	Maximum Available Power
MPP	Maximum Power Point
MPPT	Maximum Power Point Track
OCGT	Open Cycle Gas Turbine
PREPA	Puerto Rico Electric Power Authority
PRRC	Power Ramp Rate Control
PTC	PVUSA Test Conditions
PV	Photovoltaics
PVPP	Photovoltaic Power Plant
RES	Renewable Energy Source
SOC	State of Charge
STC	Standard Test Conditions
UC	Ultra Capacitors
VSM	Virtual Synchronous Machine
VSG	Virtual Synchronous Generator
2-LPF	Second Order Low Pass Filter

1 Introduction

In power systems, minimizing frequency fluctuation range plays an important role in improving stability of power systems [1]; On the other hand, system stability during frequency fluctuations is a serious concern for operators [2]. If the injected active power cannot regulate the frequency drop, frequency collapse will happen in the network [3]; Therefore, there are some published papers about technics and limits of increasing and decreasing the different kinds of produced energy during critical intervals. In addition, determining proper rate of changes in power generation by generators and power plants requires knowledge about the dynamic and topology of the system [4]. Different grid codes offers different values for the ramp rates, however, all of them are within specific ranges, in other words, values for each group of power sources are similar.

On the other hand, there is a tendency for increasing the penetration of renewable energy sources in power systems [5]. High renewable energy penetration in power systems all around the world makes electrical engineers to revise grid codes engaged with electrical transmission and distribution systems. New grid codes must consider growing renewable energy sources connected to the power systems. Solar energy is developed all around the world noticeably and it is a big concern to control the output of photovoltaic power plants and keep it in a desired range in order to not pass frequency lower threshold [6].

Grid codes in electricity industry are references determining any kind of limits, operating conditions during instabilities, operation under different circumstances, obligations for components of power systems, nominal values, controlling schemes, protection systems operations, and so on [7]. Changing rate of delivered power from any power plant of electrical network under different circumstances must follow grid codes rules [8]. If the changes are not controlled by the grid codes, the frequency will not be regulated correctly [9]. Spreading producing electricity via solar power plants in the power systems in recent years has been accelerated. Due to sun radiation changes during a day and different weather conditions, power generation in the solar farms alters frequently [10]. This variations would influence stability of the system. As a result, the frequency of system may drop below the least permitted value. Some papers suggest methods for controlling the ramp of power generation in both descending and ascending. In addition, there are different suggested values for Photovoltaics (PV) ramp rates limits in various grid codes. For example, Hawaiian Electric Company (HECO) suggests 2 MW/min and 1 MW/min for both positive and negative ramp rate values for PV (In aforementioned grid code, two values have been suggested and each of them is valid for specific hours of day) [11]. Also Puerto Rico Electric Power Authority (PREPA) offers 10%/min for both positive and negative ramps, which means ten percent of maximum power of a solar power plant is allowed to be increased or decreased in a minute [12, 13].

Some earlier papers have reviewed the Power Ramp Rate control (PRRC) methods, but in this paper, for the first time we have grouped the frameworks into two major sets including methods requiring battery storage and methods without battery storage. In addition, in final part of the paper, the most important application of PRRC is discussed as well.

2 Active power control sections

Active power control in power systems is classified into three different parts: 1) Power limiting control, 2) Power ramp rate control, and 3) Power reserve control [14]. Application of the power control schemes is described in figure 1 thoroughly.

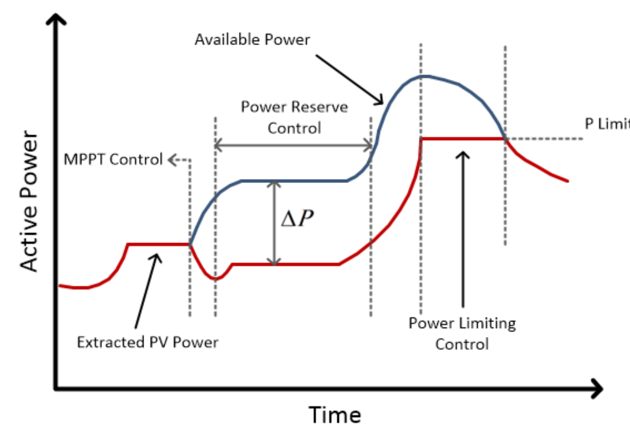

Fig. 1 Three different active power control schemes action times

While a frequency drop happens in a network, according to the drop level, each generator and power plant should add a specific quantity of active power to its generation [15]. Table 1 compares ramp rate values for some of conventional power plants specified in European grid codes. Each type has various values in different European countries regulations, so, there is a set of numbers rather than a single value available for each. As it can be seen, in this table, Open Cycle Gas Turbine (OCGT) and Closed Cycle Gas Turbine (CCGT) have been discussed. It can be understood that there are major differences even in the ramp rate of these two kind of power plants which have similar fuels. Units of numbers in table 1 is percent per minute. For example, the number 10, represents that ten percent of power plant's nominal power is allowed to be increased or decreased in a minute. Ramp rate values for PV generation in different grid codes are presented in table 2. As it can be inferred from table 2, different values have been suggested in grid codes. This variety in different grid codes could be resulted from different weather conditions, topology, as well as latitude and altitude of countries and regions. Also, different power systems have different standards for power quality and even normal frequency deviation.

In a renewable energy resource dominant system, which would be called inverter dominant grid, according to their different instruction in comparison with conventional power plants, there should be additional requirements for system to control the rate of increase and decrease in output [16]. These facilities are necessary for controlling the frequency stability of the network. In lack of this requirements--mostly controlling and storage systems—output of photovoltaic power plant will not be suitable for delivering to grid and supplying loads, because generated power may have high fluctuations. These problems are not be underestimated since they can even cause frequency collapse, also they would reduce power quality of whole network. If these fluctuations in power generation would not be controlled and compensated, then frequency collapse will happen in the network [12, 17].

Table 1 Allowed ramp rate values for conventional power plants in some European grid codes including Germany, Nordic, Great Britain, Ireland, and Baltic states

Power plant type	OCGT	CCGT	Hard coal-fired power plants	Lignite-fired power plants
Maximum allowed ramp rate ($\%P_{nom}$ per min)	8-12	2-4	1.5-4	1-2
State-of-the-art power plants				
	10-15	4-8	3-6	2-6

Table 2 Allowed ramp rate for photovoltaic generations in different grid codes

Grid code	Photovoltaic maximum allowed ramp rate
PREPA	10%/min
HECO	2MW/min and 1MW/min
EirGrid	30MW/min
Germany	10%/min

3 PV power ramp rate control

As mentioned earlier, in this paper there is a discussion about different methods of controlling and smoothing active power ramp rates for the output of photovoltaic power plants. Some suggested methods use batteries and some of them do not need any battery storage system. Also, recent platforms with Battery Energy Storage System (BESS) try to use minimum possible battery capacity, because battery life cycle is shorter than other components in power systems and the cost of battery maintenance is a serious technical economic concern as well.

It is possible to divide PV ramp limitation control schemes into two major groups. First group includes the schemes possessing BESS. The second group includes schemes without BESS. There are different suggested controlling systems in each of these two groups. For example, [18] suggest a super conducting magnetic energy storage or a bank of batteries to help operators in controlling power ramp rates. Also [19] discusses about various plans offering Maximum Available Power (MAP) for PRRC schemes to fulfill their controlling aims and providing requisite energy during shortages. Both of the sets is discussed widely in coming sub sections.

3.1 PV ramp rate control systems including battery energy storage systems

BESS includes not only batteries, but also Control and Power Conditioning Systems (C-PCS). C-PCSs with various structures have different roles and usually are multi-task components. Due to C-PCSs high expenses, optimizing their design is crucial. One of the main tasks of C-PCS is to control the state of charge of batteries [20]. In figure 2, there is the schematic of the power generation by PV facilitated by BESS. In this figure, PV Power Plant (PVPP) lines are one-way (from plant toward grid), but BESS lines are two-way which means the battery can be charged or discharged during different periods [21].

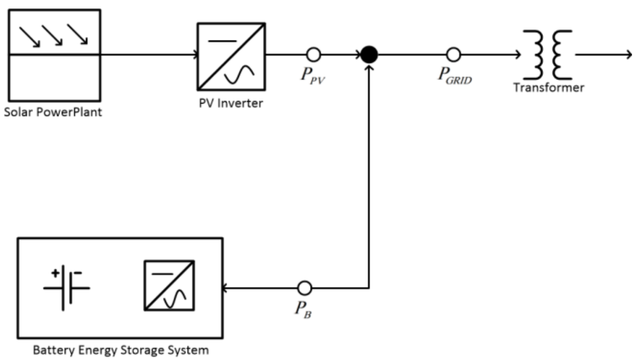

Fig. 2 Schematic of a PV power plant generation and a connected BESS to grid

PV power ramp rate can be calculated by equation 1, and if the system contains the BESS, PV power ramp rate should be calculated via equation 2.

$$R_{RATEPV}(t) = \frac{P_{pv}(t) - P_{pv}(t-1)}{\Delta t} \quad (1)$$

$$R_{RATEDG} = \frac{(P_{pv}(t) + P_B(t)) - (P_{pv}(t-1) + P_B(t-1))}{\Delta t} \quad (2)$$

Where $R_{RATED\ PV}$ represents PVPP ramp rate, P_{PV} shows PVPP generated power, Δt shows to time gap between two progressive power measurements, $R_{RATED\ DG}$ represents grid connected PVPP ramp rate where a BESS is also connected, and finally P_B refers to BESS delivered power in the specific time [9, 21]. According to charging or discharging state of batteries, P_B can be positive or negative.

In conventional ramp rate control systems, State of Charge (SOC) of BESS is specified and the value of available battery energy for helping ramp smoothing is calculated contentiously [22, 23] These classic methods are not efficient and consume big battery capacities. Also, [24] illustrates similar strategy, but the proposed scheme in mentioned paper not only describes PV ramp control, but also provides a voltage protection control. The additional control flag does not allows voltage level to exceed from a defined maximum level. The extended method has not considered reducing the costs as well. Some literatures, such as [25], explain the primary basis of conventional ramp rate controls via moving average or some similar concepts. These controlling methods have been expanded and modified in [26]. Authors of this paper have provided an algorithm that smoothens ramp in a grid with solar and wind generation. This method has been a breakthrough in improvement of the ramp rate control methods in aspect of accuracy, but it still could not satisfy economic criteria.

In grids containing only solar power resources, ramp rate limit control systems in the presence of BESS usually are based on determining desired P_{GRID} instead of P_{PV} , and this is easily explainable. While there are some batteries beside PVPP, injected power to the grid will not be equal to the power generated in PVPP, and battery charging/discharging will effect delivered power to grid. Therefore, P_{GRID} can be calculated using equation 3.

$$P_{GRID} = P_{pv} + P_B \quad (3)$$

In some cases, such as earlier mentioned SOC controlling system included method, if there is no time limit for battery charging, batteries lifetime decreases dramatically. Each day, battery will be forced to keep energy in full charge level for an unnecessary long period of time, while it can be charged later and closer to the energy serving interval for ramp control or other services. As a result, this is another downside for this type of schemes. To tackle this problem, it is suggested to use data from previous days as a feedback. These data help batteries to keep energy in shorter periods of time in batteries' cells, and also designing BESS for this kind of systems requires less battery capacity [21, 27]. However, the reliability of the feedback is a serious concern for this framework. In addition, there are other papers and works trying to reduce capacity of battery storage used in PRRC. Results of Conventional Exponential Smoothing (CES) and Moving Average (MA) methods describe how different could be the capacity of BESS in a singular system using different methods [28] but picking the right methodology should take place carefully, because lack of enough reliability could cause disastrous outcomes. Numerous proposed schemes for controlling PV ramp rate with battery storage systems are inspired by represented method in [22]. Authors of [22] have proposed a BESS-based method. In this grid connected approach, batteries could be charged or discharged according to the circumstances of grid and insolation. Also moving average is the main authenticator of required energy in PRRC. However, there is a dead band in this scheme in order to define an allowed range instead of just a constant number. In other words, while the ramp rate is within a range, there will be no added energy from battery. Some of other schemes have tried to optimize different parameters in the mentioned scheme or extract some additional features to it in order to improve some characteristics or add some new feature. In other words, scheme in figure 3 is a classic PV power ramp rate control systems including battery storage. Also, many papers, such as [27, 29-31], have discussed about battery requirements and sizing for microgrid with renewable energy sources and PRRC. Different constraints are considered in order to find the best answer. Most of effective constraints are about the reliability of system, economic limits, and PRRC slope. However, each research have paid more attention to some meters, as a results, each work has identical output.

Forming Hybrid Energy Storage System (HESS) to reduce capacity of required storage is the main idea of some of former works. HESS combines the benefits and desired features of different storage technologies to cover disadvantages of each individual storage technology. Proposed HESS in [32, 33] includes two groups of storage systems, one consists of a storage group formed by Ultra Capacitors (UCs), and another one consists of Li-ion batteries. UCs have low capacities but rate of their discharge is unlimited. On the other hand, Li-ion batteries have high capacities with limited discharge rate characteristic. Main objectives of dispatching duty between li-ion and UCs are as follows:

- When HESS should absorb or supply power, and the power has significant quantity, at the beginning moments UCs take action and in other cases li-ions take action.

- When batteries supply or absorb power, if required power exceeds batteries maximum C-rate, UCs supply the required capacity [32, 33].

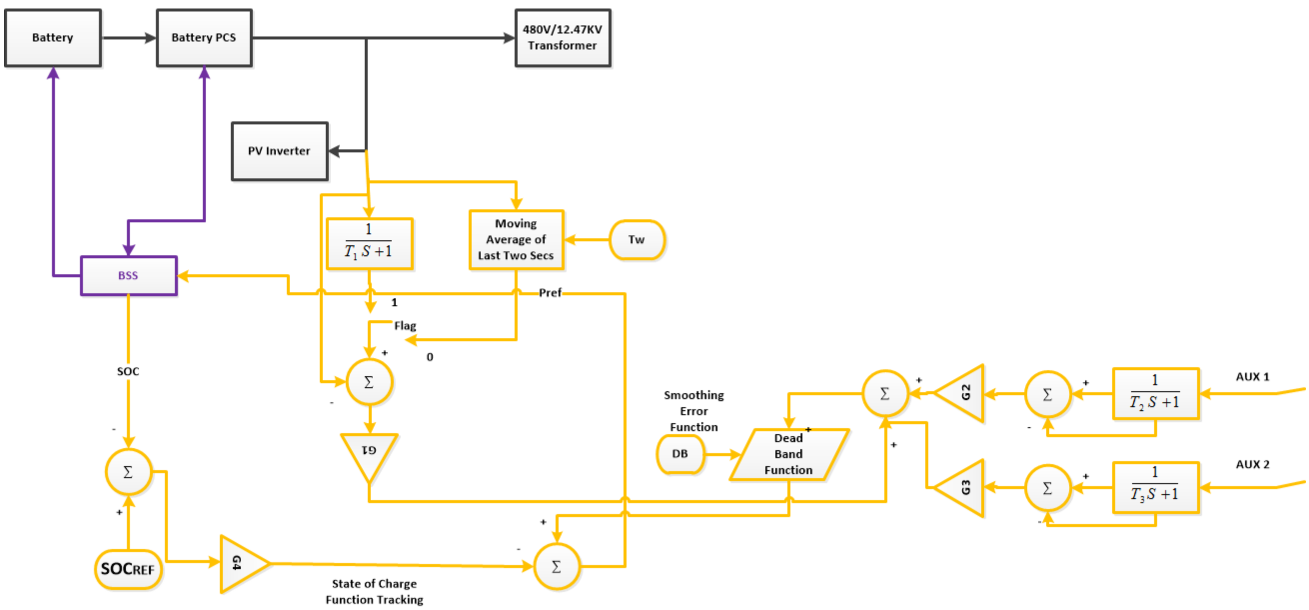

Fig. 3 schematic of the proposed scheme in [22].

Authors of [25] have discussed a ramp rate controlling system using Electric Double Layer Capacitor (EDLC). This method is based on MA. EDLC absorbs excessive power when there is surplus generation. In other words, EDLC will not allow ramp rate to exceed from upper limit. In addition, when system comes short in power, EDLC releases the saved energy and will not allow ramp rate to drop below lower limit. Also, mechanism of EDLC has been discussed in [34] for levelling renewable energy sources outputs. In the mentioned paper, there is a discussion about configuration of Current Source Inverters (CSI) additionally.

In conventional systems, power ramp rate control is usually based on MA. MA has a huge historical impact on present value of ramp rate [35]. Figure 4 shows a 20-minute MA. Effect of present value in comparison with past values is very little in this MA oriented system. Also, it can be seen inside red circles, when real value has no fluctuation, MA still fluctuate dramatically, besides, real value and MA have big undesired differences, as a result, this is a big problem for this approach [36].

In such a PV dominated system, ramp rate of MA of a PV with variable output at the kth time instant can be defined using the following equation:

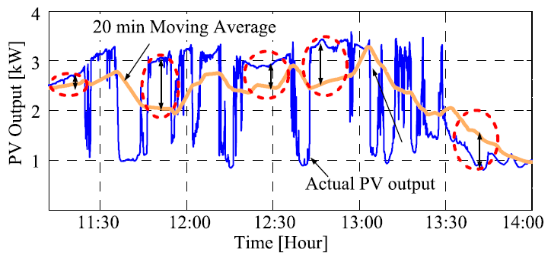

Fig. 4 A 20- minute moving average for PRRC [35]

$$MoRR(k)=\frac{1}{w}\times\frac{\sum_{i=0}^{w-1}P_{DC}(k-i)-\sum_{i=0}^{w-1}P_{DC}(k-1-i)}{t(k)-t(k-1)}$$
$$=\frac{1}{w}\times\frac{P_{DC}(k)-P_{DC}(k-w)}{t(k)-t(k-1)} \quad (4)$$

where, *MoRR(k)* is the moving average ramp rate of PV panel's DC output, *w* is the length of the moving average window, P_{DC} is PV panels' DC power output, and *t(k)* is proportional time with the *k*th time instant.

In [37] the authors have proposed a new strategy for ramp rate control. This strategy is a powerful approach for cloud passing. In this strategy, there is another power source for compensating PV power uncertainty.

According to the proposed framework in [37], the output power of inverter can be determined with following equation:

$$P_{INV}=\eta_{INV}\times(P_{DC}+P_{COMP}) \quad (5)$$

Where, η_{INV} is the converter efficiency coefficient and P_{COMP} is output power of external power source for compensating ramp rate power shortage. In order to calculate changes of P_{COMP} for obtaining a proper ramp rate, following calculation is written down, adopted from [37]:

$$\frac{dP_{INV}}{dt}=\eta_{INV}\times\left[\frac{dP_{DC}}{dt}+\frac{dP_{COMP}}{dt}\right] \quad (6)$$

$$\frac{dP_{COMP}}{dt}=\frac{1}{\eta_{INV}}\times\left[\left.\frac{dP_{INV}}{dt}\right|_{des}-\eta_{INV}\times\frac{dP_{DC}}{dt}\right] \quad (7)$$

The discussed strategy solves the problems of MA-based methods including unwanted fluctuations and big difference between actual output and MA of the figure. Also, authors of [38] have gathered and compared the results of various methods, including MA, Exponential Moving Average (EMA), Low Pass Filter (LPF), and second order Low Pass Filter (2-LPF).

In novel power grids containing PRRC, batteries continuously will be charged and discharged. According to batteries characteristics, there is an allowed range for charge and discharge rates of batteries. If the level of energy of batteries exceeds the limits, it will cause some problems and affects PRRC. Studies in [39] have turned attention to the mentioned issue. In [39], authors for tackling this drawback have described the SOC of BESS as a flag. While the SOC is in a normal range, the flag is 1 and while it is out of normal range, the flag is 0. Only during the time that the flag is 1, saved energy in BESS is allowed to take part in PRRC and increase the flexibility of PRRC, otherwise BESS should be disconnected to PRRC system and batteries must put its SOC into the allowed range. Also some papers such as [40] have suggested mixing diverse methods and develop new means of PRRC with reduced amount of required battery storage. However, reliability and speed of these approaches must be questioned.

3.2 PV ramp rate control systems without battery energy storage systems

Using batteries in power systems results in significant increase of initial costs. Also, battery life cycle is less than other power system components life duration. In addition, regular maintenance of batteries must be considered, otherwise, serious problems such as reduced reliability of system will take place. Therefore, using batteries has to be avoided if it is possible.

In most of grid connected PV systems, there is no battery storage systems. BESS-based PRRC systems contain storage system equipment to fulfill the defined duty. The major and common problem of BESS-based PRRC methods is their huge costs, as a result, mostly they cannot pass economic obligations. By and large, the penetration level of batteries in power systems should be minimized as much as possible. So, almost in every paper, using less BESS capacity is known as an advantage [41, 42].

One solution for controlling delivered power and PV ramp rate is setting scheduled power point under Maximum Power Point (MPP). This method helps systems to avoid implementing BESS. This cluster of PRRC frameworks require some reserve power for helping the stability of systems during fluctuations. It is noteworthy that reserved power should meet standards and grid codes obligations, and maximum level of reserved power should not exceed limits. Operating under MPP provides another capability for PVPPS calling Frequency Sensitive Mode (FSM). Providing reserve active power in PVPP improves frequency stability. During a frequency drop, the mentioned reserved power can be released, so system frequency could get back within its nominal range [12, 43, 44]. Besides, if required active power reserve is supplied from other sources, PVPP can work on its MPP. This operation mode is possible in hybrid networks including energy storage systems, but the forming such systems with BESS is too expensive [45]. Nowadays, different hybrid systems have been designed and implemented; so there are various means for their instruction and management. In this regard, many papers have discussed each component and management schemes of hybrid systems, and it seems that hybrid systems could solve many of existing problems about energy. For instance, they could come handy in the field of running out of oil and gas resources around the world. In addition, most of the generated power in hybrid systems are clean and makes no air pollution [46, 47]. However, there are many issues with high renewable energy penetrated power grids which must be resolved.

In some methods, such as the proposed one in [12], PV power ramp could vary when higher or lower ramp rate is required. In fact, a framework with flexible ramp is more useful than schemes with a static value. Another PV PRRC strategy has been proposed in [45] which is based on weather and solar radiation forecasting. In this strategy, two forecasting systems have been implemented, one is long term forecasting and another one is short term–for next 30 minutes. Sensors help the system to forecast weather, and cloud passing path. If clouds path is identified as covering PVs, controlling system will take action. When sensors recognize a cloud as a barrier in coming hours, after a specific period, a new ramp rate with bigger slope than standard ramp rate slope will be set in order to help keeping steady increase of the power generation. Weather forecasting systems and sensors have been explained widely in [45, 48, 49]. The forecasting methods are still improving and higher accuracy for forecasting methods is crucial, as a result, frameworks requiring forecasting can grow better in future works by higher accuracies and less errors.. In addition, in [50, 51] there are two other proposed scheme using deep learning and machine learning to forecast coming hours weather and solar radiation. Two different dataset from past months are used as training input of the processes, but deep learning methods cannot predict sudden weather changes. Besides, [52] explains a novel method to control PV ramp rate according to measured PV-side voltage. In other words, error between reference voltage and measured one is the feed of feedback of the controller block. Authors of [52], not only propose a new developed method, but also represent a comprehensive comparison with traditional BESS-based method.

There are some proposed methods for controlling PV power ramp rate just for controlling the ramp during incremental cycles. There is a method based on conventional Maximum Power Point Tracking (MPPT) with some modifications in [24]. Conventional MPPT always tracks the highest available power, for example at t_1 in v_1 voltage, maximum power is available. Conventional MPPT changes I-V curve of PV in order to reach the v_1 and maximum power. If the insolation changes, then at t_2, there will be a v_2 voltage which can deliver new maximum available power. In proposed modified MPPT, there is a stable and predefined maximum rate of changes ($\Delta P_{\max}$) . During solar insolation increase, rate of changes in delivered power should be compared with $\Delta P_{\max}$. If $\Delta P_{\max}$ is bigger, the system is allowed to go to the new MPP, but if $\Delta P_{\max}$ is lower than predicted rate of change, a new voltage should be calculated proportional to $\Delta P_{\max}$. It means that the new voltage should be proportional to a P which causes the ΔP equaling to $\Delta P_{\max}$ [53, 54]. Also, figure 5 is presenting a PRRC with modified MPPT flowchart. Modified MPPT requires additional PVPP capacity, as a result, this leads to an additional cost. However, this cost should be compared with cost of implementing BESS.

In a specific zone of California state, potential ramp rate of an amount of average sized PVPPs are presented in [55]. In order to have an accurate estimation of their output, PVs tilt angle, azimuth angle, wind speed, and ambient air temperature for calculating PVs surface temperature are measured. Also, converters efficiency is represented in equation 8 adopted from [56]:

$$\eta_{ac} = \frac{pf}{0.007 + 1.009pf + (0.0975pf)^2} \tag{8}$$

Where, pf is performance factor and can be calculated by:

$$pf = \frac{P_{\mathrm{mod},dc}}{kW_{ac}} \tag{9}$$

Where, $P_{\mathrm{mod},dc}$ is DC power output of the PV sites and kW_{ac} is rated capacity of PVPP in PVUSA Test Conditions (PTC) or Standard Test Conditions (STC). Calculations, results, and comparisons for different days and scenarios are listed in [55]. 86 distributed PVs have been considered in this study. Local data, satellite data, and irradiance data are used to obtain more accurate models and results. Also, geographical parameters of territory is highly involved in the models and results.

4 Basis of different PRRC algorithms designation

Studying different papers demonstrates that there are various sources of data to initialize PRRC in different algorithms. For example, some algorithms are sensitive to fast climate changes, such as clouds passing, and some are not. Architecture of algorithm determines the algorithm belongs to which of two aforementioned major groups. Also, some BESS-based algorithms have tried to combine different data and methods to use minimum possible storage facilities. In [57] authors have presented an ESS control strategy that requires one quarter of conventional BESS-based PRRC battery storage capacity. In mentioned study, BESS control system starts to work a moment before clouds passing. This is possible with using short term weather forecasting. However, this is just an initial research and it should be improved in next works. Also, Authors of [58] have represented another PRRC based on weather forecasting data. This method can stop power fluctuation of PVPPs resulting from irradiance changes or clouds passing. In [59] there have been presented another algorithm for omitting generation fluctuations due to cloud passing. The research also considers some constraints for SOC as an additional feature. Some proposed algorithms have combined different methods for reaching better results and possessing better and various capabilities. For example, the proposed method in [60] needs both historical samples and short-term forecasting. In fact, this method requires three inputs: 1) historical samples of PV-BESS, 2) forecast of maximum available PV power, 3) current of SOC of BESS. These inputs will help the algorithm to have optimal answers and fulfill grid codes requirements.

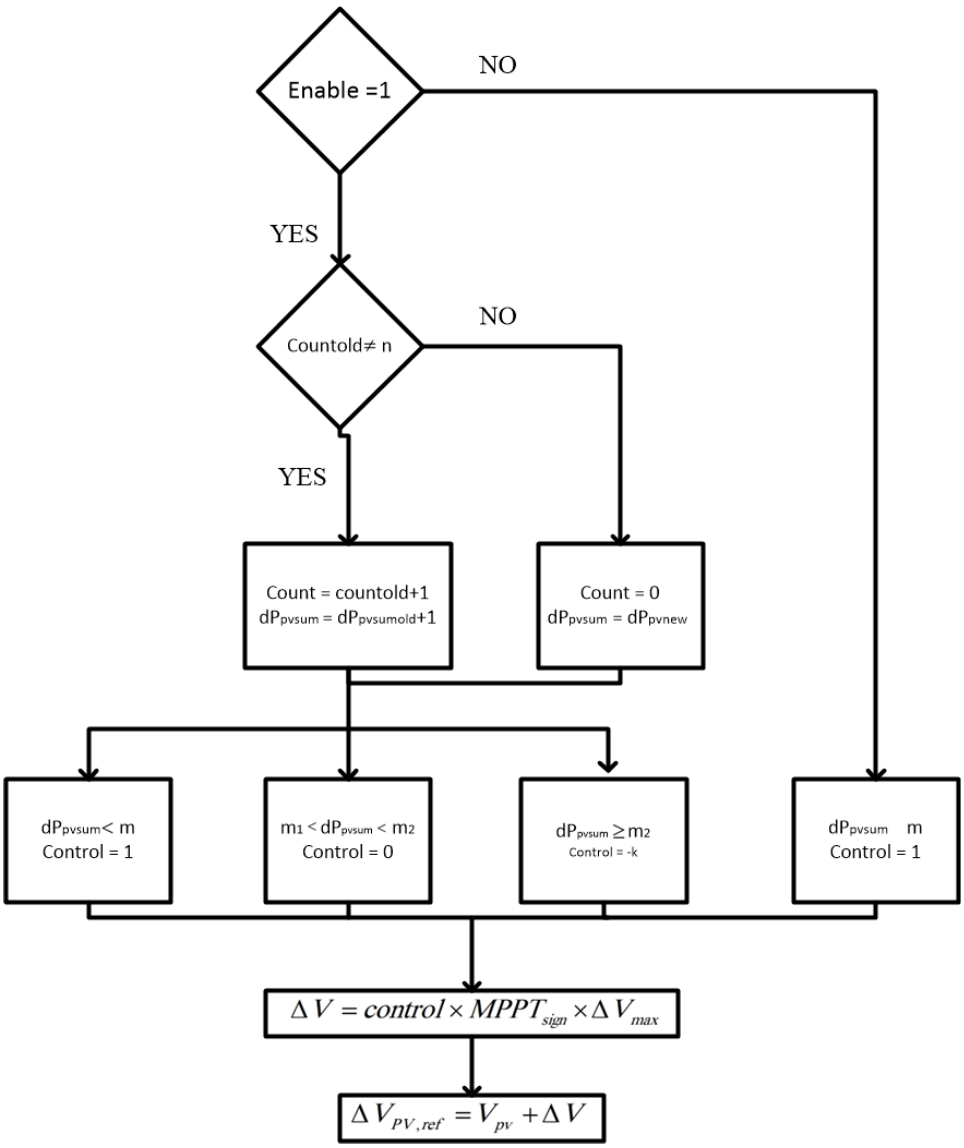

Fig 5 Flow chart of power ramp rate control by modified MPPT

In addition to discussed methods, in [61] not only uncertainty of PVs power generation is considered, but also changes of load is involved in proposed PRRC method. However this is a limited study with some formulations and it is not applied on a real system.

5 Further uses of PRRC

In addition to grid codes requirements, PRRC for renewable energy sources output is critical according to many other aspects. In [62] there have been discussed a method for controlling frequency in low inertia power systems using Virtual Synchronous Machine (VSM). One of the important parts of VSM is PRRC. In some papers including [63, 64], VSM is called Virtual Synchronous Generator (VSG). Conventional power systems used to have static inertia constant but in modern power systems, regarding to high Renewable Energy Sources (RES) penetration and wider scenarios, inertia constant is variable. Also, average of inertia constant has decreased dramatically. VSM is a practical solution for compensating inertia constant reduction [65].

Additionally, a novel research in [66] have focused on time delays effects on ramp rate control. Time delay can occur due to communication delay, processing delay, converters respond delay, and battery time constants. According to the size of PVPP, some new constraints for maximum ramp rates are proposed. With new maximum values for ramp rates, time delay cannot cause unacceptable fluctuations in the power ramp rate [66].

6 Conclusion

There are obvious differences between implementing and not using BESS in PRRC systems. Using BESS can make the system more reliable, more secure, and make operating in MPP possible, but on the other hand, not participating BESS can reduce the costs dramatically and reduce the necessity of maintenance obligations.

Table 3 concludes requirements and unique advantages of some of the most important previous investigations. Conventional PRRC systems for PVPPs require battery storage systems. Some new control systems suggest not to use any BESS, but not to track the maximum power point. Not tracking the maximum power point in PVPPs means installing more solar panels and equipment without using them during normal operation mode. New strategies consider both reliability and economic issues. Storage capacity and unused PV equipment must be minimized. Also, more accurate forecasting systems about solar radiation leads PRRC to use less storage capacity and operate more closely to the maximum power point. On the other hand, using battery and not implementing BESS in PRRC both can take place in different ways. Each of these strategies have advantages in comparison with others. Using battery in a system adds a noticeable cost for initial investment and maintaining the system. Also, not using batteries reduce reliability of system and keep not unleashed power in PVPPs.

More researches can take place in this field in order to find hybrid framework with more accurate forecasting methods and reliable, economically justified, and fast PRRC approaches. Also, the new frameworks should be adjusted for different values. On the other hands, proposed approach must target one of stand-alone or grid connected systems , because there are huge and clear differences between these two systems, as a result, the characteristics of the PRRC will be highly influenced by the type of grid.

Table 3 Brief review of some remarkable references

Ref. No.	[21]	[25]	[26]	[32]	[33]
Requirements	-ESS -SOC -Moving Average	-BESS -Moving Average	-BESS -SOC -Hybrid Grid	-BESS -Hybrid Storage System -Electrolyzer	-Hybrid Storage System (UCs + Li-ion batteries) -SOC
Specifications	-Reduced Battery Size	-Capacitor voltage control	-Analyzing Various SOC	-Reduced Battery Size -Considering Demand Side Requirements	-Optimized Storage System
Ref. No.	[35]	[12]	[45]	[50]	[48]
Requirements	-Moving Average -SOC -Hybrid Storage System (Flywheels+ UCs + Li-ion batteries)	-Just Basics and Some Reserve capacity	-Sensors -Forecasting System	-Deep Learning -Previous Data about Weather	-Forecasting Daily and Long term Irradiance -Measurement Devices
Specifications	-Simple Cost Analyses	-No ESS -Considering Grid Code	-No BESS	-No BESS	-No BESS

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