Reactive Power Control Strategies for Solar Inverters to Increase the Penetration Level of RE in Power Grid

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Abstract— Integration of Distributed Generation (DG) in active grid depends on the grid parameters viz. strength of the network, voltage etc. Network voltage is one of the limitations for penetration of Renewable Energy (RE) based DG into the active power grid. Solar Photovoltaic power generation is a key source of Renewable Energy Sources (RES), which is integrated through the highly efficient and multi-functional inverters. Capability of Solar Inverters (SI) can be utilized to provide the voltage support during critical system need on a 24/7 basis. During night, entire inverter capacity can be used for reactive power support. During the critical voltage condition in the daytime, SI capacity left after the PV power generation can be utilized to improve the voltage stability of the system without any RE curtailment. This paper presents potential reactive power control schemes for SI, considering enhanced utilization of the inverter reactive power capability to enhance the voltage regulation at the Point of Common Coupling (PCC) under the physical limitation of the inverter. The Solar Inverter Control (SIC) schemes are incorporated in the optimal power flow (OPF), and formulated as an optimization problem, where, the inverter control schemes are applied to maximize the total distributed generation (DG) penetration and enhance the distribution/transmission network utilization in a typical power grid. Various case studies are presented and compared to evaluate the performance. The results show that the proposed reactive power control scheme can significantly increase the wind penetration levels up to 81% depending of the network constrains and integrated RES.

Keywords— Solar inverters, reactive power control, distribution system, distributed generation, inverter control scheme, optimization.

I. INTRODUCTION

The active power distribution network operation with the integration of variable renewable energy sources, storage units, and dynamic loads are attracting a lot of interest due to substantial benefits in maximizing the penetration of RES. However, the risk of voltage violation in the power system is increased due to increasing the penetration of DGs/RES [1]-[3]. This problem can be handled by effective voltage regulation and reactive power support into power system. Advanced solar inverters can perform functions including both active and reactive power control in addition to their main function of converting DC power to AC power [4]. These functions include voltage regulation, power factor control, ramp-rate control, Low Voltage Ride Through (LVRT)/High Voltage Ride Through (HVRT)/Fault Ride Through (FRT) , frequency control, etc. Various grid support functions offered by SI are presently being demonstrated on real distribution and transmission systems in different countries, to motivate their rapid deployment [5]–[6] in support of RE integration.

Current Indian power grid experiences a substantial growth in RE integration to meet the electricity demand and its commitment to reduce emission intensity up to 33-35% by 2030 vis-à-vis environmental loading levels in 2005. An ambitious target of integration of 175 GW RE generation by 2022 has been set to fulfil the same. Integration of such massive amounts of RE which are intermittent and distributed in the power system pose serious challenges to grid operations. Studies and analysis show that extra flexibility investments in the Indian grid are needed on fast track for managing the RE resources efficiently. Proper managing of RES integration into the grid can mitigate these problems. Nowadays, grid interconnection standards are currently being revised to facilitate the adoption of smart inverter functions [7]–[8].

Augmentation of generation to cater increasing demand needs is facing the problem of voltage and limited transmission capacity of the power system, RES is one of the solutions for the increasing power demand and environmental pressure. Thus, latest research has focused on further maximization of RES penetration with optimal utilization of existing system infrastructure to maximize the benefits in terms of improvement in real power loss, loadability, and voltage profile. The advanced power electronic converters provide an opportunity for further optimization of the operation of RES interconnecting inverters under their physical limitations.

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There is substantial research reported on effects and challenges of high penetration of DGs mainly solar and wind at distribution level [9]. The common impacts of RES integration are voltage fluctuations [10] and stability due to variability in nature and dynamic peak load scenarios. Chances of voltage limit violations during both peak SPVG and peak load may lead to challenging issues with increasing RES integration, especially in distribution systems. The substantial investment in voltage regulation devices and technology is inevitable to mitigate the mentioned problem. DG penetration can be increased with increased voltage regulation of the network [11].

In the literature, many voltage regulation techniques and devices such as tap settings of Tap Changing transformers, Volt/VAr controllers, capacitor banks and FACTS devices have been proposed [12]. These conventional methods are not adequate to handle such a fast voltage deviation in real time operation of the system. In addition, the installation of these devices is not a cost-effective solution. Therefore, most of the studies advocated that utilization of Energy Storage Systems (ESS) and Advanced Power Electronic Devices (APED) available in the interconnected distribution system are the effective and economical solutions [13].

In most of the ADS management studies, only DG reactive power capability is accounted within the specified power factor limit [14]. The discussion given in [15] have revealed the importance of power electronic technology for wind and solar DGs, however, the methods of effective utilization of the inverters are not properly addressed. In [16], the active distribution network management scheme which includes coordinated voltage control, energy curtailment and power factor control methods has been proposed to enhance and maximize the utilization of distribution system infrastructure and facilitate maximum wind energy penetration into the power system. However, in these studies, reactive power and power factor capabilities of solar inverters is not explored in day/night time operation. This literature thus reveals that utilization of capability of RES interconnecting inverters to improve the stability, reliability, performance, and resilience of the entire grid is one of the most effective research areas. However, power electronics converters have some physical limitations such as i) current flowing through the converter, ii) DC link voltage iii) modulation index of converters and iv) ratings of the interfacing cables [17]-[18] which have not been properly accounted in the above literatures.

This paper seeks to fill the gap by considering the physical limitations of SPVI in the maximization problem of wind power penetration into ADS. This problem can be modeled as an optimization problem and solved by metaheuristic techniques to avoid the mathematical complexity. In this paper, an improved harmony search-based optimization technique is used for solving the problem of maximization of RES integration using maximum utilization of available reactive power capability of solar inverters. In this paper, different schemes for optimal utilization of SI are proposed to maximize the wind energy penetrations into ADS. Application of proposed SPVI schemes is demonstrated for 33 nodes ADS where various SPVI and wind power generators with different capacities are installed in the system.

II. REACTIVE POWER CAPABILITY OF INVERTER

RES (Solar and wind) in ADS are integrated with fast and multifunctional inverters. Inverter controlled reactive power capability of the wind power generator is utilized for voltage control of the hybrid ADS. However, these inverters are constrained by various parameters mainly energy conversion approach, active power output, power factor limits, R/X ratio of the system, load types, and rating of inverters [19]. These constraints are very important for the realistic analysis and operation of the interconnected power system. The SI can independently control the active and reactive power output in comparison to simple inverter-based wind generation system. Moreover, it has been found that wind farm inverters can also support the reactive power similar to the solar PV inverters, but with the different limitations viz. wind-turbine technology, generator types, line limit, thermal limit and location. For instance, induction generators deployed at the wind farm only consumes the reactive power from the grid. Alternatively, additional sources of reactive power such as capacitor bank and reactive power compensators can be provided to compensate the reactive power supplied from the grid. Moreover, doubly fed induction generators and synchronous generators are mostly used for wind power generation which have the ability to control the supply at interconnecting point [20]. However, solar photovoltaic-based system has a wide range of reactive power control capability i.e. 5-10 % (daytime) to 100% (nighttime) in comparison to wind inverters. Therefore, authors have used this range of reactive power control capability of SI for voltage regulation of ADS by which RES (wind) penetration is maximized in order to meet the power demand with minimum RE curtailment and optimal utilization of power system.

A. *Rating and capability of SI*

In general, PV inverters are rated according to rated peak active power of PV panel and specified reactive power limit. SI rating and capability curve is application specific and depends on the size of PV panel, climatic conditions, and interconnection standards of the country [21]. Solar inverters are not an infinite source/sink of the reactive power [22]. Reactive power capability of SI can be evaluated as follows:

I. For specified active power rating of SPV panel (P_{SPV}) and rating of the inverter (S_{SI}), maximum reactive power limit (Q_{SI}) can be ideally evaluated as in (1).

$$\boldsymbol{Q_{SI}^{rated} = \sqrt{S_{SI}^2 - P_{SPV}^2}} \tag{1}$$

II. According to the German Standard VDE-AR-N 4105 [34], all solar power plants should comply with the power factor (PF) adjustment in order to support the grid operations. For specified P_{SPV} and power factor (PF_{PV}) of SPV DG system, maximum Q_{SI} can be evaluated as follows

$$PF_{PV} = \frac{P_{SPV}}{\sqrt{P_{SPV}^2 + Q_{SPV}^2}} \tag{2}$$

$$Q_{SI}^{PF} = P_{SPF} \tan(cos^{-1}(PF_{SPV})) \tag{3}$$

$$Q_{SI}^{PF} = P_{SPV} \frac{\sqrt{1-PF_{SPV}^2}}{PF_{SPV}} \tag{4}$$

Hence, maximum reactive power limit of SI is,

$$Q_{SI}^{max} = \min(Q_{SI}^{PF}, Q_{SI}^{rated}) \tag{5}$$

B. *PQ capability curve of SI*

As already mentioned that active and reactive power of the SI can be independently selected, but it must follow the certain physical limits. PQ capability of the inverter is constrained by mainly three quantities, inverter current, maximum AC output voltage which is calculated from DC voltage and impedance of interconnected cable/transformer [19]. Equivalent AC system can be represented by equivalent voltage source V connected to an inverter with the cable/transformer of equivalent impedance X_{eq}, as in Fig. 1. The output voltage of the inverter is V_C which is depended on input DC voltage.

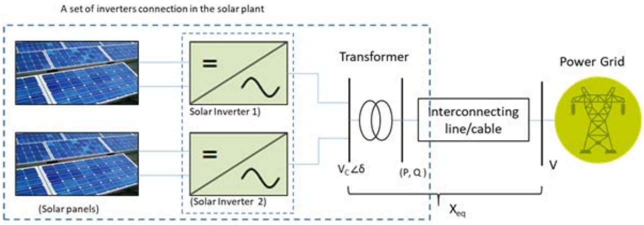

Figure 1 Block diagram of SI interconnection

Maximum Active Power: The maximum active power (P) of the inverter can be equal to the rating of the inverter at unity power factor. The instantaneous active power output of inverter depends on the solar irradiance and control setting of the inverter if maximum solar PV generation is extracted and accordingly inverter control setting is optimized for reactive power support.

Maximum Reactive Power: The PQ capability of the inverter can be expressed by mathematical relation given in (6) [35]. For an ideal voltage control bus, *V* remains to be fixed. Hence, the PQ capability chart is shown in Fig. 2 with parameters as *V=1 pu* and V_{cmax}*=0.985 pu* and X_{eq}*=0.264 pu*.

$$\sqrt{\left(Q_{SI} + \frac{V^2}{X_{eq}}\right)^2 + P_{SI}^2} \leq \frac{V_{cmax}V}{X_{eq}} \tag{6}$$

$$\Longrightarrow Q_{SI}^{max} = \left(\sqrt{\left(\frac{V_{cmax}V}{X_{eq}}\right)^2 - P_{SI}^2}\right) - \frac{V^2}{X_{eq}} \tag{7}$$

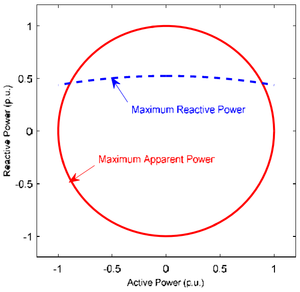

Figure 2 Ideal PQ capability curve of solar

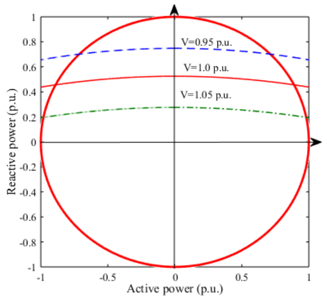

Figure 3 PQ capability chart of the inverter with varying |V|

The reactive power supplied by the inverter depends on the AC voltage (V) of the associated bus. If V drops, more reactive power is injected by the inverter as shown in Fig. 3.

III. PROPOSED CONTROL SCHEMES AND PROBLEM FORMULATION

Capacity of solar inverters must be selected according to maximum peak output of SPV (rated kWp). According to historical data of renewable resources, it is worthy to note that good amount of solar and wind is available in western India. In a typical year, 45 % of the time there is considerable active power generation from solar, while, at the same time, there is a wind generation (40 % of the time). Only 0.12-0.17 % (i.e. 10-15 hours in a year) of the time, there is rated active power generation from solar plants [23]-[24]. Thus, at-least 10 % reactive power capability of SI could be effectively utilized for 99 % of the time annually. Whereas, 100 % capacity can be effectively utilized when solar generation is zero (i.e. 55 % of the time). This analysis motivates to develop a control scheme for max utilization of SI for maximization of RE penetration and utilization of distribution network without RE/load curtailment.

A. *Proposed control schemes*

A normal size of the inverter is selected with a reactive power capability of 0-100% of rated SI. However, one can also select an oversized inverter (105-110 % of rated Solar Generation). The proposed control schemes for utilizing the reactive power capability of SI are described as follows:

Full Reactive Power Mode (FRP-Mode): When the solar power generation is minimum (zero in night-time), the full reactive power capability of SI (rated capacity) can be utilized to maintain the system voltage within the specified limit which allows to increase the wind penetration in the ADS. This scheme is effective in the night-time and early morning. From (1) amount of reactive power in FRP Mode can be calculated as follows

$$Q_{SI} = \sqrt{S_{SI}^2 - 0^2} = S_{SI} \tag{8}$$

In this, Q_{SI} physical limitation of inverter discussed in section II is not incorporated which may lead to unrealistic evaluation. It must follow the PQ capability chart given in Fig. 2. Hence, from (7) and (8), instantaneous reactive power (Q_{SPV}) supplied to grid is evaluated as

$$Q_{SPV} = \min\{Q_{SI}, Q_{SI}^{max}\} \tag{9}$$

Partial Reactive Power Mode (PRP-Mode): Here, utility controller needs to be specified with the utilized SI capacity based on experiences of solar plant output (P_{SPV}). In general, most of the time active power generated by solar plant is less than the 90 % of rated plant capacity. Therefore, 10 % of reactive power capability of SI can be utilized to maintain the system voltage and increase the wind power penetration. This scheme is activated for sunshine hours. However, this scheme may not be fit for the cases when P_{SPV} is more than the 90 % (i.e. About 10-15 hrs/year).

Optimal Reactive Power Mode (ORP-Mode): Under this scheme, reactive power capability of SI is utilized up to its full capability all the time. This scheme is activated when P_{SPV} generation is more than 90 % of rated. Depending on P_{SPV}, *ORP-Mode* provides variable reactive power capability, unlike the previous schemes, continuously, which can be determined by using (10).

$$Q_{SPVI} \le \sqrt{S_{SI}^2 - P_{SPV}^2} \tag{10}$$

However, after consideration of physical limitations, the maximum reactive power supplied by the inverter is limited and evaluated with the help of capability chart as follows

$$Q_{SPV} = \min\{\sqrt{S_{SI}^2 - P_{SPV}^2}, Q_{SI}^{max}\} \tag{11}$$

In order to achieve continuous reactive power support, PV inverter can be operated in a combination of above-proposed control schemes under the intermittent RES integration.

B. *Formulation of objective function*

The main aim of this paper is to maximize the RE (wind) power in the system with optimal utilization of existing inverter integrated with solar power plant. The proposed SI control schemes are implemented to achieve the objective. The objective function is formulated as in (12) subject to the power system equality and inequality constraints given in (13)-(18).

Objective function:

$$Max\ F = \textstyle\sum_i P_{wind\_i} \tag{12}$$

Subject to:

$$P_{SS} + \sum P_{SPV} + \sum P_{wind} - \sum P_{Load} - P_{Loss} = 0 \tag{13}$$

$$Q_{SS} + \sum Q_{SPV} + \sum Q_{wind} - \sum Q_{Load} - Q_{Loss} = 0 \tag{14}$$

$$V_{i\,min} < V_i < V_{i\,max} \tag{15}$$

$$Q_{SS}^{min} < Q_{SS} < Q_{SS}^{max} \tag{16}$$

$$Q_{SPV}^{min} < Q_{SPV} < Q_{SPV}^{max} \tag{17}$$

$$S_{SI} \le S_{SI}^{max} \tag{18}$$

P_{ss}, Q_{ss}	Active and reactive power supplied by the substation
P_{SPV}, Q_{SPV}	Active and reactive power generated by solar PV
V_i	Voltage magnitude
P_{wind}, Q_{wind}	Penetrated wind active and reactive power
P_{SPV}, Q_{SPV}	Penetrated APVG active and reactive power
S_{SI}	Rated value of solar plant inverter

Where,

Proposed objective function is solved by using optimal power flow embedded Dynamic Harmony Search Algorithm (DHSA). The formulation, however, is generic enough and any other optimization method can be utilized. DHSA is simple for implementation and less dependent on control parameters. This algorithm has ability to dynamically adjust the bandwidth between the permissible limit of decision variable towards the optimal solution. More details of this algorithm can be found in [25].

IV. SIMULATION AND RESULT DISCUSSIONS

A. *Test system*

The performance of the proposed control schemes is demonstrated on 33-bus typical distribution system. Single line diagram of the test system is given in the Fig. 4. In the first case this distribution system is modified to ADS by adding two DGs: wind power with a rated capacity of Maximum 8 MW at the 25th node and solar generation of 1.5 MWp at the 6th node. Detailed data of the system can be found in [26]. Voltage deviations are assumed to be with ±6% at each bus in the ADS.

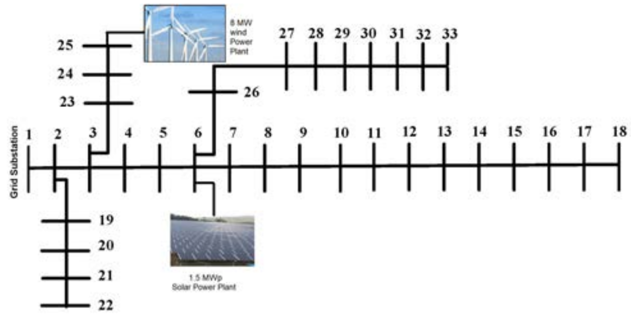

Figure 4 Modified 33-node active distribution system

The proposed control schemes are simulated in MATLAB, with and without consideration of physical limitation of solar inverters for two different case studies.

B. Simulation using DHSA

The DHSA is a metaheuristic algorithm which is used to solve the formulated maximization problem (12). Simulation steps of the proposed control schemes is given in the flow chart Fig. 5. In order to achieve the optimal solution with least computational efforts and time, an appropriate selection of algorithmic parameters is very important.

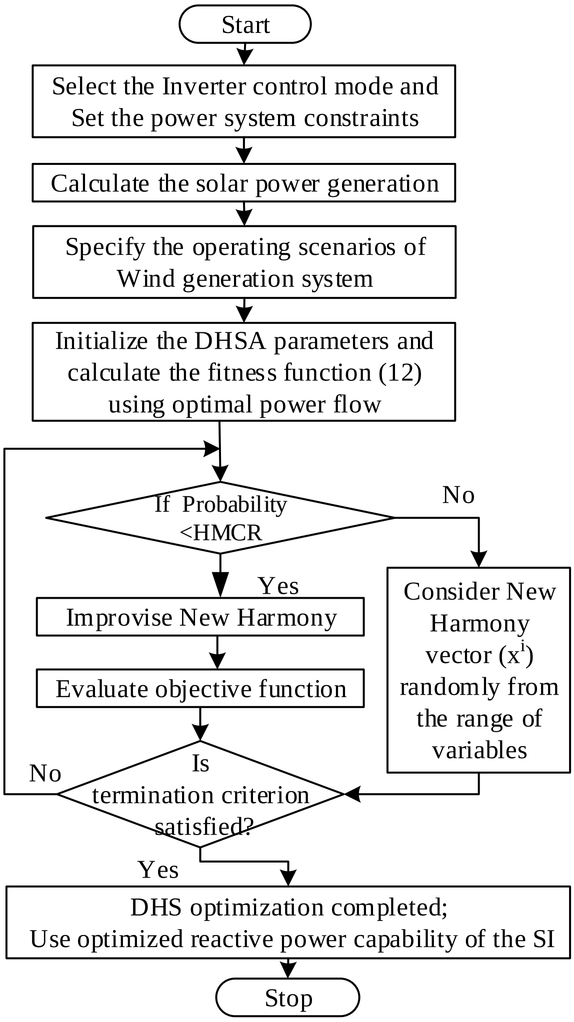

Figure 5 Flow chart of DHSA optimization algorithm for control application of proposed schemes

The DHSA has only two control parameters to be tuned: Harmony Memory Size (*HMS*) and Harmony Memory Considering Rate (*HMCR*). For tuning of these parameters, a rigorous study is done by varying them for the above test system within the permissible range given in [25]. The optimal parameters of the DHSA is given in Table I.

Table 1 Tuned parameters of the optimization algorithm

DHSA parameters	**Value**
HMS	15
HMCR	0.95
NI (No of pitch adjustment/stopping criterion)	100
Range of *PAR*	[0.2, 0.99]
Bandwidth (BW)	[0.5, 0.001]

C. Case study-I

In this case, an ideal inverter as in [27] is assumed. SPVI control schemes are implemented with the intent to maximize the wind power penetration at node 25. The SPVG of fixed 1.5 MWp is located at node 6 which is a sensitive node for system loss.

In this study, three different power factor scenarios of wind DG are selected as unity, 0.98 lagging and Controlled

Power Factor (CPF) within the range of ±0.95 power factor. Results obtained for each scenario are compared with corresponding base case results. Results for proposed schemes and base case are given in Table II. Average (%) increase with respect to base case is determined using (15)-(16) simple calculations and given in Table III. These results show the substantial increase in wind power penetrations. Different penetration levels are shown in Fig. 6. It can be concluded that SI utilization scheme is one of the most effective solutions to enhance the wind power penetration.

$$Average\ P_{wind\_25} = \frac{P^{units}_{wind\_25} + P^{0.98\ lag}_{wind\_25} + P^{CPF}_{wind\_25}}{3} \quad (15)$$

$$\%\ Increase\ in\ P_{wind\_25} = \frac{P_{wind\_25} - P_{wind\_25\_base}}{P_{wind\_25}} X100 \quad (16)$$

Table II

MAXIMUM PENETRATION OF WIND POWER IN DIFFERENT SCHEMES

Wind DG operating scenarios	**P_{wind} (MW)**			
	Base case	*FRP-Mode*	*PRP-Mode*	*ORP-Mode*
Unity PF	5.1	5.4	5.3	5.3
0.98 lagging	4.5	4.7	4.7	4.6
CPF	5.1	5.1	7.2	7.7

Table III

AVERAGE (%) INCREASE IN WIND POWER PENETRATIONS WITH PROPOSED CONTROL SCHEMES

Reactive power control schemes	*FRP-Mode*	*PRP-Mode*	*ORP-Mode*
Average (%) increased in wind power penetration with reactive power support from SI	3.4	16.5	19.3

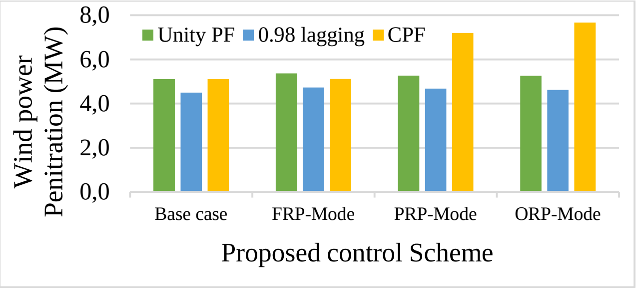

Figure 6 Maximum wind penetration at node 25 by using fixed SPVG at node-6

During night time, it is very difficult to maintain the voltage within the specified range with maximum penetration of wind power without utilization of reactive capability of SI. Voltage scenario of ADC with different level of DG penetration is shown in Fig. 7, where it can be seen that voltage at node 18 is not improved by maximum penetration (5.08 MW) of wind DG. However, it can be improved to specified voltage limits using reactive power capability of SPVI integrated with SPVG. Maximum penetration of wind DG may lead to a violation of upper voltage limits (Fig. 7 Red line). Thus, wind power curtailment is forced. This problem of power curtailment can be minimized using reactive power capability of SI. Maximum wind power penetration (7.1 MW) with the proposed scheme under the specified voltage limit is shown in Fig. 7 (black thin line).

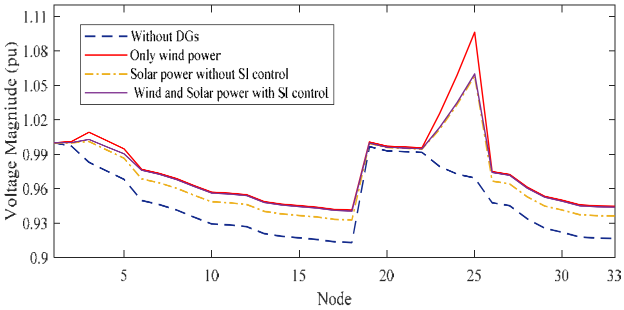

Figure 7 Voltage profile of 33 node system at the different levels of wind and solar penetration.

D. *Case study-II*

In this study, IEEE 33-bus system is modified by integrating two wind DGs and three PV DGs to demonstrate the control schemes to maximize the total wind penetration in the ADS. The capacity of all DGs is given in Table V. Inverter limitations and hourly load/generation scenarios are considered to evaluate the efficiency and effectiveness of the schemes. Hourly load and generation scenarios with normalized values of load and RE (solar and wind) generation are depicted in Fig. 8.

Table IV

RATING AND LOCATION OF DGS

Parameters	Solar Photovoltaic			Wind	
Location (Node)	6	10	27	25	30
Rating (MW)	1.5	0.5	0.4	8	0.5

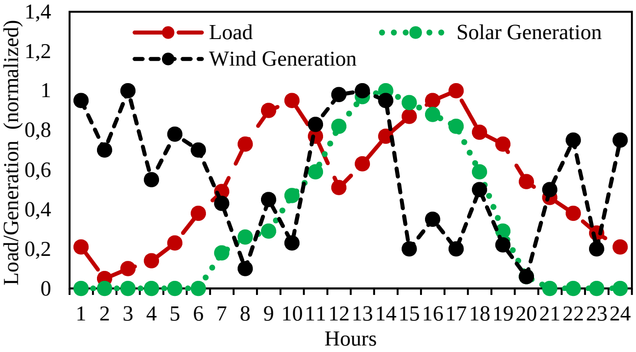

Figure 8 Hourly operational scenario of load and generation.

Hourly voltage profile of the system without DG integration is shown in the Fig. 10 where, lower limit voltage violations at different nodes (18th, 30th and 33rd) are depicted. Voltage magnitude of the ADS is highly depended on type and size of the DGs. Due to tremendous development in DG technology and environmental pressure, RE based DG integration is an economical way to supply the demand and improve the voltage profile of the ADS. However, network characteristics and physical constraints of the power system are forced to limit the maximum penetration of such DGs. The hourly voltage profile of the ADS integrated with the DGs of rated capacity (Table IV) is shown in Fig. 10 where critical upper limit voltage violations at 25th nodes are observed when wind farm is integrated. Total wind energy penetration capacity in a typical day is 10.35 MWh with the selected wind generation scenario in Fig. 8. There are two methods to avoid voltage violation due to RE penetration, RE power curtailment, and reactive power support. In this case, to operate the ADS within a specified voltage range (±6%), wind power is forcefully reduced by 47.46 % with respect to the total capacity of wind generation in the typical day. The voltage at different nodes under the power curtailment approach is given in Fig. 11. Although node voltages are within the limits, DGs' power curtailment method may not be appropriate since power generated by PES is wasted. Reactive power control scheme proposed in this paper for voltage regulation of ADS with the aim of maximum power penetration is a most promising approach. In this case, the proposed control scheme is to maximize the penetration of wind power into the system under the specified voltage limits.

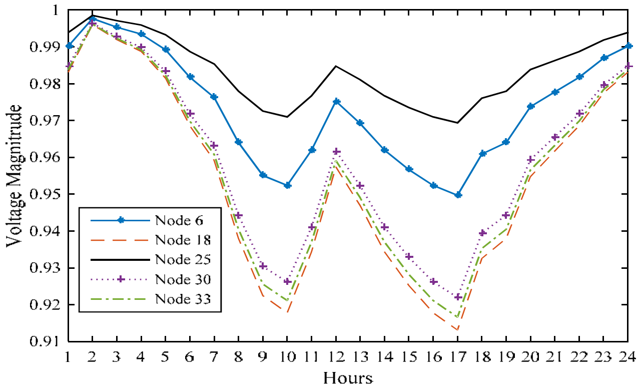

Figure 9 Hourly voltage magnitude of the system without penetration DGs.

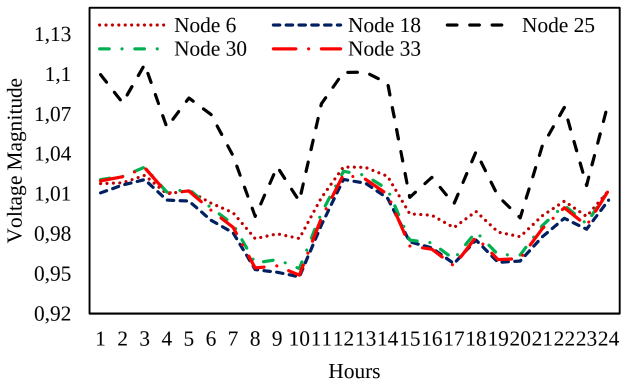

Figure 10 Voltage scenario of ADS integrated with DGs without reactive power control

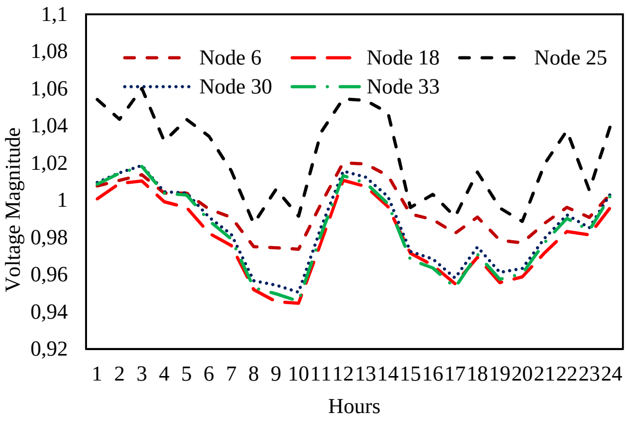

Figure 11 Voltage profile of 33 bus ADS integrated with DG under 47.46 % wind power curtailment.

Proposed control schemes have been implemented to the DGs connected in ADS to avoid the wind power curtailment while keeping all power system constraints like voltage limit of the network, solar inverter and other operational constraints under consideration. The simulation results with ideal SI characteristics and capability curve discussed in previous sections are also compared. Total wind energy penetration on a typical day is enhanced by 81.34 % of the Power curtailment method. Total wind power supply under different control schemes is given in Table V. It can be observed that energy supplied by wind DG is reduced by 302 kWh when physical limitations of the inverters are imposed in the proposed scheme. Hourly voltage profile of the critical nodes with ideal SI is given in Fig. 12. Whereas, the hourly voltage profile with consideration of physical limitation of the SI is given in Fig 13.

Table V
WIND POWER PENETRATION UNDER DIFFERENT METHODS

	Power curtailment method	Proposed scheme (using ideal SI)	Proposed scheme (Using SI capability curve)
Wind energy for the typical day (MWh)	52.717	95.606	**95.304**

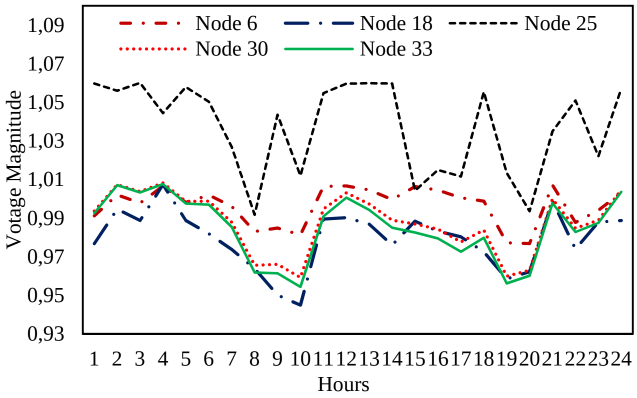

Figure 12 Hourly voltage profile of critical nodes in ADS with the proposed control scheme for ideal SI.

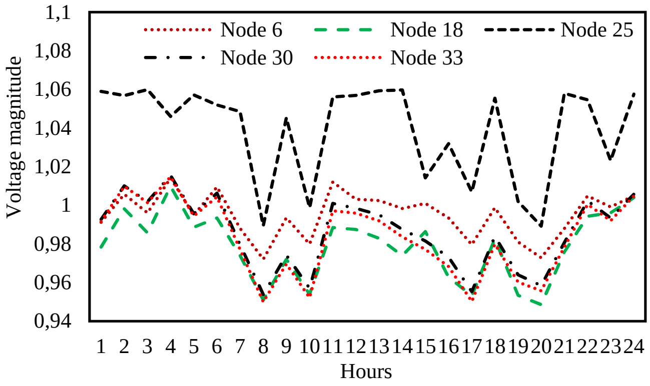

Figure 13 Hourly voltage profile of critical nodes in ADS with proposed control scheme considering the physical capability of SI.

V. CONCLUSIONS

Reactive power control schemes of the solar inverters are presented for maximization of RE penetration and network utilization which could help to minimize the RE power curtailment and network argumentation. These control schemes can be implemented in the existing SI at the solar plant to support the dynamic reactive power and network voltage throughout the day. Proposed SI control schemes and impact of physical limitation of inverters are demonstrated for 33-node radial distribution system for a typical day. From the demonstration of FRP-Mode, PRF-Mode and ORP-Mode of operation of SI, it was found that reactive power capability of existing SI, especially when SPVG active power generation is minimum (early morning, evening and night) significant for the enhancement of wind power penetration into the ADS. In the test system, total wind energy penetration on a typical day is enhanced by 81.34 % in comparison to the Power curtailment method. In this paper, reactive power capability of inverters connected to solar plant is only considered. However, proposed schemes can be implemented on the inverters connected in wind farms having sufficient reactive power limits to support grid after fulfilling their local requirements. These schemes have vital future scope to implement in existing solar and wind inverter to minimize the investment in reactive sources in the active distribution system. The proposed control scheme can be an effective tool for the siting and sizing of RES during the initial planning stage.

It can also be suggested that slightly oversized inverters may be more helpful and economical to provide continuous reactive power support to the grid without/Minimum deployment of additional reactive power sources such as Static Synchronous Compensator (**STATCOM**), Capacitor bank, Flexible Alternating Current Transmission System (**FACTS**), etc.

VI. ACKNOWLEDGMENT

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