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(*Article*)

Centralized and Decentralized Reactive Power Control of PV Inverter Connected To Distribution Systems: Comparative Study

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ABSTRACT

The current trend of renewable integration in networks is being fueled in large part by the inescapable rise in electrical power consumption, the depletion of conventional power generation resources, and the widespread concern about global warming. One of the most significant issues brought on by this developing trend is the overvoltage produced by distributed generation units that are interfaced at the consumer end and power injected at random nodes. Contrary to typical grids' preset power flows, this results in bidirectional power flows, which need the use of a modern, coordinated, and reliable voltage control method with a minimal amount of communication infrastructure. To stop the voltage variations brought on by excessive solar integration in distribution networks, a centralized based Volt/VAR regulating strategy is proposed. To evaluate the effectiveness of the suggested system, we employ MATLAB Simulink on an IEEE-15 bus standard. The results show the superiority of the centralized strategy on the decentralized one.

Keywords: PV system; inverter; voltage regulation; centralized reactive power control methods.

I. Introduction

Distribution networks are typically built on the premise that there is no on-site generating, so the actual power flow is from the upstream feeder to the downstream loads. PV integration into the electric power system is rapidly rising. This increases output from renewable energy sources but decreases reliability and power quality, increases overvoltage at the point of common connection, frequency disruptions, and grid stability problems, among other issues.

Overvoltage or voltage rise happens when PV penetration rises, causing the substation to receive electricity from load buses in the other direction, which could change the feeder voltage profile and raise bus voltages, and making the grid unstable Some of the technological fixes discussed in the literature try to reduce the effects of changing voltage and achieve efficient voltage regulation throughout the network. This research uses a volt/var control method that utilities can utilize to optimize the voltage profile along their feeders altering the quantity of reactive electricity that is added to the grid. The ability of inverter-based solar generation to produce reactive electricity is constrained based on semiconductor switch devices' ability to carry current. The extra capacity can be employed as a reactive power supply or absorber when the actual power injection falls below the inverter's rated power. Modern PV systems using inverters connected to grids are able to actively manage reactive power because they have inverters that can do so, likewise referred to as management and control of the voltage.

[1] examines the various reactive power control strategies that the grid code recommends. The suggested approach adjusted the common Q(V) characteristic and used centralized reactive power management. According to modeling data, the constant power factor method causes a voltage increase across the board, consuming a significant amount of the distribution grid's reactive power. The bus voltage can be controlled within the grid code using the conventional Q(V) approach. The distribution grid is supported by more reactive power than the constant power factor technique does, though. Comparable to the traditional Q(V) approach in terms of reactive power, Compared to other control methods, the suggested method may better regulate the bus voltage.

[2] meant to facilitate reactive power supply in smart grids using end users. The CSDVC (centralized support distributed voltage control) is suggested as a means of controlling the input of reactive power into potential buses. Utilizing -decomposition, the control regions are produced. The suggested algorithm significantly improves voltage profilebased on simulations of the IEEE 33- and 69-bus distribution test systems, and the amount can have an impact on the precision of voltage management. It has been demonstrated that adding more local areas improves the voltage profile in systems without constant voltage DG, and the opposite is true in systems with constant voltage DG. It has also been demonstrated that the quality of voltage mitigation increases as the number of potential buses increases. Additionally, It is shown that the proposed CSDVC algorithm offers excellent voltage mitigation even when local regions are unable to lower voltage to desirable levels or when local control centers are inoperable.

The reactive power capability of smart inverter-based PV systems and accessible OLTC (On-load tap changers) are used to produce effective management employing coordinated control to handle It is demonstrated that the suggested CSDVC algorithm provides effective voltage mitigation even in the absence of functional local control centers or when local areas are unable to reduce voltage to desired levels. The buses are taken into account individually because their sensitivities differ from those of other zone buses. Less tap changes were found to be necessary when the bus with the highest sensitivity was controlled. Because of reduced Q-V droop regulation, the operating PV system voltage bandwidth is narrower than the OLTC. Additionally, as reactive power absorption rises, the PV system loading rises as well. When the OLTC and Q-V droop are operated concurrently but independently, tap modifications become more necessary.

With the suggested appropriate coordinated control, the tap change is reduced and the voltage magnitudes are also within the permissible range. In addition, it is possible to look into the effects of different forms of autonomous control and how well they perform when there is an OLTC [3]. In Low Voltage (LV) networks where photovoltaic (PV) penetration is substantial, [4] examines how centralized and decentralized systems are used for voltage regulation. To synchronize dispersed PV converters with a centralized device in conventional LV grids, large investments in new communication and control infrastructures would be required. The use of distributed PV converters as an option for voltage regulation is investigated, showing that it can aid in maintaining the voltage in the grid connection points even without coordination between them and/or with a centralized unit. In order to understand how the setup of the voltage controllers inside PV inverters affects their performance while taking into account the restrictions for reactive power injection, this study will look at how these controllers are configured. The relationship between distributed PV converters and centralized devices (static var compensators and on load tap changers) is also looked at to see if there may be any extra advantages in these circumstances.

[5] perform a case study to analyze the steady-state response of a large distribution network with 3434 buses when relatively moderate- and high-capacity renewable PV systems either produce or consume reactive power and present a three-phase Volt/Var-control method. The first case study used OpenDSS to model an actual substation distribution system with 3434 buses, including feeder J1 and thirteen PV systems that could control Volt/Var. According to the case studies, high-capacity PV systems (i.e., 31.2% of total peak generation of the distribution system) that could not control Volt/Var increased overvoltage along the feeder. In contrast, high-capacity PV systems that could control Volt/Var mitigated such an increase in voltage. The first case study determined the reactive power by the relationship between the predefined slope and the bus voltage’s current magnitude, ignoring the impedance sensitivity of the feeders. Thus, this study presented a three-phase Volt/Var-control method that could regulate the positive-sequence magnitude of three phase voltages by using a positive-sequence sensitivity impedance matrix with power-factor constraints.

[6] Overvoltage regulation and loss minimization in DN with high penetration of PV systems is considered in this paper. To prevent unacceptable voltage rise, a droop-based reactive power control (RPC) and a fair active power curtailment (APC) algorithm are proposed. The proposed algorithms maximize the achieved PV generation and guarantee the voltages of all buses in the acceptable range. All PVSs participate in the APC fairly using only local measurements, without any communication links, centralized control and information about the structure and parameters of the DN. The necessity of using RPC capability of PV system inverters is also proved. In addition to voltage regulation, the proposed RPC algorithm minimizes the system losses and loading of feeder transformer. Effectiveness ofthe proposed algorithms was verified using dynamic simulation of the IEEE 33 bus test system.

[7] Photovoltaic (PV) inverters are traditionally designed to operate with unity power factors. In order to use reactive power capabilities of smart inverters, in this work two strategies

are analysed: limiting the amount of active power delivered or oversizing the inverter. The first of these options implies a reduction in the PV production and therefore, it would lead to reduced earnings for the PV system owner. On the other hand, oversizing the PV inverter allows having reactive power compensation capabilities, while delivering full power output from its PV field.

[8] Focuse on voltage regulation methods for PV systems with ancillary services. One of the strategies encouraged in the German GC for LV, the Q(U) strategy, was implemented and simulated on an European LV benchmark grid. Results showed that this regulation method can keep the voltages at PCCs below the 3% limit but with the drawback of absorbing more reactive power than needed. This is because each PV inverter calculates the necessary compensatory reactive power depending on the voltage at the corresponding PCC and based on a Q-U droop characteristic. An optimized Q(U) algorithm using a centralized controller which is able to dispatch the minimum amount of reactive power to each PV inverter has the purpose to improve the existent solution encouraged by the system operators. The method considers all the voltages at the PCC of each grid-connected PV system in the network and calculates the minimum absorption of reactive power. To develop such optimized control strategy, communication infrastructure is needed in order for the central controller to transmit the calculated values of reactive power for each PV inverter which participates in the voltage regulation process. The benefits of implementing the optimized Q(U) algorithm are: a better usage of the PV inverter capacity which leads to increased PV capacity in the network, lower transformer loading and lower network losses.

[9][10] utilized the reactive power capability of PV inverters to mitigate voltage deviations is being promoted. In recent years, droop control of inverter-based distributed energy resources has emerged as an essential tool for use in this study. The participation of PV systems in voltage regulation and its coordination with existing controllers, such as on-load tap changers, is paramount for controlling the voltage within specified limits. In this work, control strategies are presented that can be coordinated with the existing controls in a distributed manner. The effectiveness of the proposed method was demonstrated through simulation results on a distribution system [11][12].

A proposed strategy depending on central and secondary controllers is presented. The central controller has two PI controllers to determine the ratio of compensating batteries' currents in each bus based on their VU values and to ensure the same resultant compensating batteries' currents at all distribution feeder's buses. If there are no AC-coupled batteries or insufficient SoC in a specific phase, the others could accomplish the task. Three sequential scenarios of loads/PVs combinations are applied to validate the applicability of the proposed controller scheme. Three cases are applied based on the batteries' SoC. Simulation results indicate that the system response reaches a steady-state in 100 s almost, which represents 100 intervals to investigate the response of the proposed VU mitigation technique [13][14].

This essay's remaining sections are organised as follows. In Section 2, the decentralised reactive power control strategies, in Section 3, the centralised reactive power control strategies

Section 4 constructs a 50Hz, 15-bus radial distribution system and presents simulation results in section 5. The paper is concluded with a discussion in Section 6.

II. DECENTRALIZED VOLTAGE CONTROL SCHEMES

Distribution Control of Reactive Power, as previously stated control reactive power at each inverter, is a candidate strategy for mitigating the overvoltage problem generated by DGs. According to 10-min average voltage variations, Reactive power management techniques can be categorized into four main categories, which are as follows:

a. Power factor as a function of the active power generated by the PV is controlled by the cos ϕ (P) control.
b. Fixed power factor (fixed cos ϕ)
c. Reactive power injection controls that are fixed (fixed Q).
d. Q(V) control (local voltage-dependent reactive power).

In this paper we addressed constant reactive power strategy which (Fig.1) ensures that the quantity of reactive power supplied or absorbed by the PV inverter will remain constant regardless of the other system variables that are present. To develop an effective Q point using this technology, knowledge of PV power profiles and load power is required. Due to the methodology's neglect for additional system factors like voltage, reactive power adjustment will be provided by the PV inverters even when it is not required.

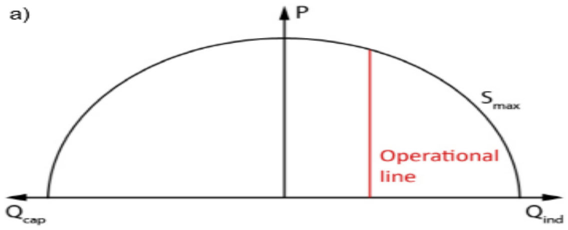


Fig. 1: Operational windows for (a) Fixed Q control

III. CENTRALIZED OR COORDINATED VOLTAGE CONTROL SCHEMES

Evaluation of current control strategies and coordinated operation of distributed energy resources (DER) are required to address issues with security, voltage control, and quality of supply in the upcoming South African distribution network. A key idea for the future is the incorporation of DER, It might address voltage control problems. In order to manage voltage in active distribution networks, this study looked at some of the most recent international studies on DER technologies, strategies, control techniques, and optimization methods. The literature demonstrates that in order to alleviate grid stability issues, a control strategy must be put into place that makes use of the technologies, control methods, monitoring, and communication that are already available. To support the evolving network requirements, real-time voltage control methods will need to be put in place. A coordinated operation and integration of DER, employing intelligent control methodologies, could reduce voltage control issues in the future South African distribution network.[15] Sam Weckx, Carlos Gonzalez, et al. provide an approach that uses PV inverters in imbalanced distribution grids to adjust voltage by combining a central and local control method. It has been established the three-phase, four-wire grids in imbalanced that the control of reactive and active power must be given special consideration due to the neutral-point shifting influence. As a function of the PV power generated, a firstorder spline defines the reactive and constrained active power that PV inverters govern. Each and every spline's parameters are changed on a regular basis, i.e. every 15 minutes, by a central convex optimisation programme. In addition, Reactive power is used nearly optimally and there is little constraint on active power thanks to central optimisation of the local parameters. This makes it possible for local controllers to react to shifting weather conditions swiftly, and demonstrate how the suggested control keeps the voltage within the permitted range while suffering less losses than comparable local control methods. It is capable of using active power fairly and consumes less active power than active power-using local control techniques [16].

Comparison between decentralized and centralized:

	Advantages	Disadvantages
Centralized	• Wide coordination • Ease of hardware implementation • Robust • Possibility to ensure global and local objectives	Requires highly reliable and wide communication network • High investment • Extensive control • Data sharing is difficult • Subject to single point failures • Computation complexity • Difficulties when global information is not available
Decentralized	• No coordination • Cost saving - limiting the need for large investment • Control actions are locally determined • Not reliant on the wide area communication system • Able to provide voltage support • Avoids the need for complex data management	• Limited coordination • Ignores global objective • Focuses on the local objective • Possibility of conflicts when several local controls exist

IV. SYSTEM MODELLING

The centralized impact of DG on distribution loss and voltage profile is applied on the system consisting of a 15-bus, 50Hz radial distribution system which shown in (Fig.2).

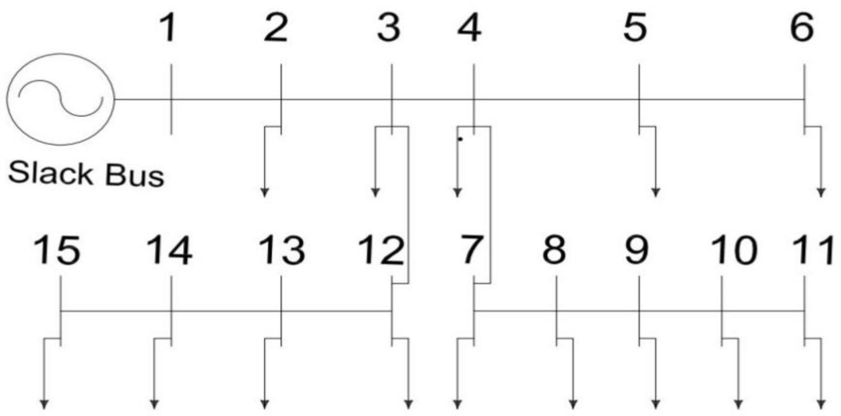


Fig. 2: 15-bus Radial Distribution System

Centralized reactive power control methods:

(Fig. 2) uses a 15-bus, 50Hz radial distribution system to show the centralised effect of DG on distribution loss and voltage profile. The line parameters and load data are shown in tables (1, 2). Based on 30MVA and 11kV basis, the data. We use the following centralised reactive power control techniques:

- We take system data and run load power flow.
- We use genetic algorism for optimization.
- Genetic algorism can take system data and define PV location.
- choose reactive power output of each PV which make voltage within range and minimize losses.
- Q output from genetic algorism can be used as a set points for PV.
- We can repeat this each hour or at expected update for load.

With limitations on bus voltages, the reactive power injection optimization scenario seeks to reduce network power losses.

This problem can be stated as follows:

Min {Plosses (QG) = $\sum_{j=1}^{n-1} R * Ij^2$ for all j= 1, 2, . n, } (1)

Subject to:

$$Vmin \leq Vj \leq Vmax \quad (2)$$

$$Qmin \leq QG \leq Qmax \quad (3)$$

Where Ploss is power losses in transmission system which is
the objective function to be minimized.

Where Ij is the current flowing in the transmission system.
QG is the injected reactive power from pv inverter.
Vj is voltage at bus j.

We used genetic algorism with the following setting:
Population type: double vector
Creation function: constraint dependent
Scaling function: rank
Selection function: stochastic uniform
Crossover fraction: 0.8
Mutation function: constraint dependent
Cross over function: constraint dependent
Migration direction: forward
Migration fraction: 0.2
Migration interval: 20
Penalty factor: 100
Function tolerance: 1e-6
Constraint tolerance: 1e-3

Table 1: Line parameters of 15-bus radial distribution system

Bus No	From	To	R (pu)	X pu)	R (ohm)	L (H)
1	1	2	0.00315	0.075207	0.012705	0.000965
2	2	3	0.00033	0.001849	0.001331	2.37E-05
3	3	4	0.00667	0.030808	0.026902	0.000395
4	4	5	0.00579	0.014949	0.023353	0.000192
5	5	6	0.01414	0.036549	0.057031	0.000469
6	4	7	0.008	0.036961	0.032267	0.000474
7	7	8	0.009	0.041575	0.0363	0.000534
8	8	9	0.007	0.032346	0.028233	0.000415
9	9	10	0.00367	0.01694	0.014802	0.000217
10	10	11	0.009	0.041575	0.0363	0.000534
11	3	12	0.0275	0.127043	0.110917	0.00163
12	12	13	0.0315	0.081405	0.12705	0.001045
13	13	14	0.03965	0.102984	0.159922	0.001322
14	14	15	0.01061	0.004153	0.042794	5.33E-05

Table 2: Load data of 15-bus radial distribution system

Bus. No	P (kw)	Q (kvar)
2	312	31.5
3	742.5	76.5
4	1437	147
5	633	67.5
6	199.5	18
7	957	99
8	484.5	49.5
9	319.5	33
10	420	43.5
11	3255	33
12	198	21
13	43.5	4.5
14	241.5	24
15	208.5	21

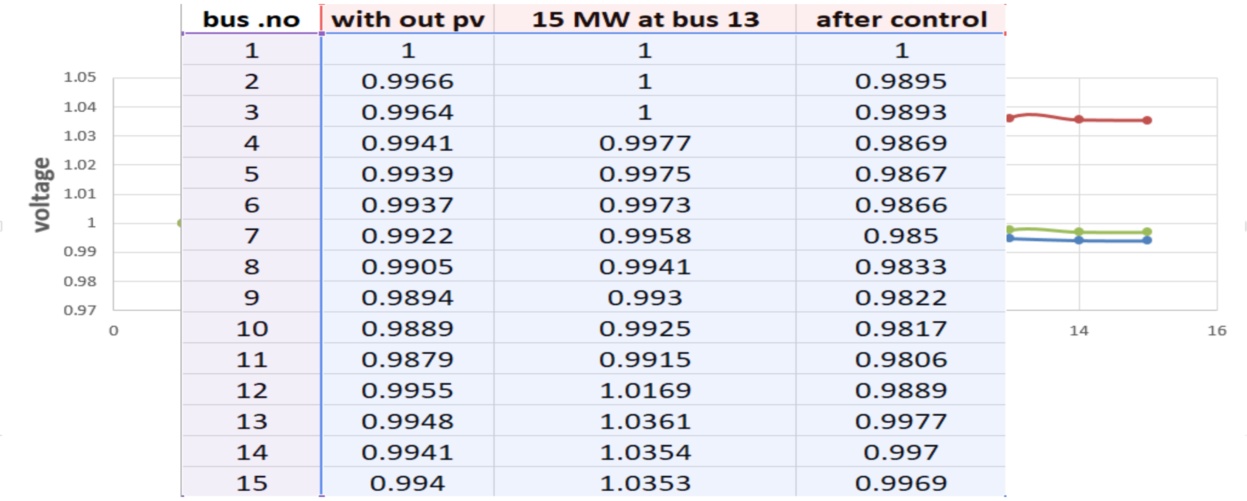
V. SIMULATION AND RESULT

A. Centralized reactive power control senarios:

1) Senario 1: after adding one PV = 15 MW at bus (13)

In this case one PV system with rating of 15 MW is added at bus 13, leading to overvoltage overall the system. Then we apply centralized reactive power control method to mitigate the over voltage as shown in (Fig.3).

Table 3: **The node voltage at adding PV at bus 13**



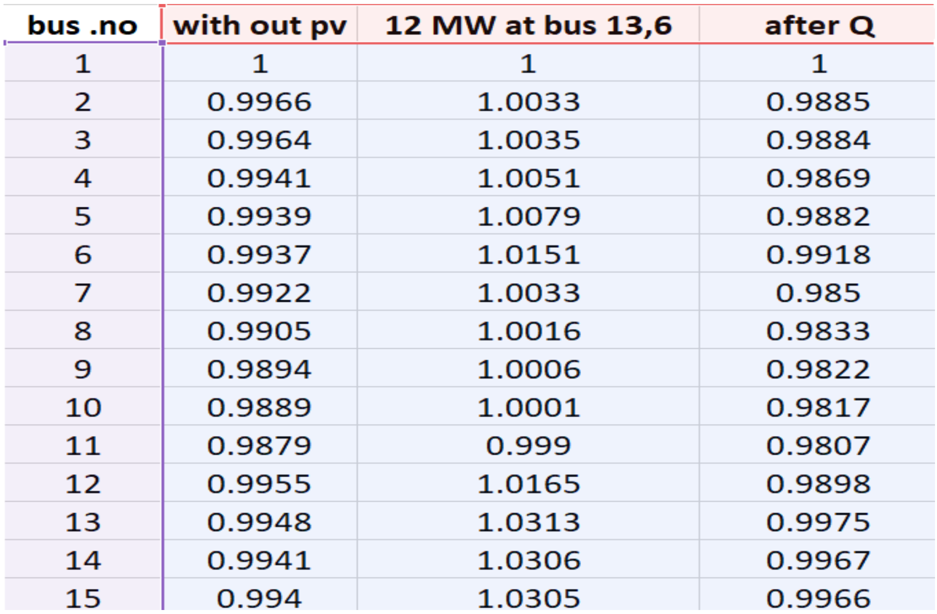
bus .no	with out pv	15 MW at bus 13	after control
1	1	1	1
2	0.9966	1	0.9895
3	0.9964	1	0.9893
4	0.9941	0.9977	0.9869
5	0.9939	0.9975	0.9867
6	0.9937	0.9973	0.9866
7	0.9922	0.9958	0.985
8	0.9905	0.9941	0.9833
9	0.9894	0.993	0.9822
10	0.9889	0.9925	0.9817
11	0.9879	0.9915	0.9806
12	0.9955	1.0169	0.9889
13	0.9948	1.0361	0.9977
14	0.9941	1.0354	0.997
15	0.994	1.0353	0.9969

Fig 3: The voltage profile after adding PV at bus 13

2) Senario 2: after adding two PV systems each pv =12MW at buses (6,13).

In this case two PV systems with rating of 12 MW are added at bus 6 and bus 13, leading to overvoltage overall the system especially at buses 6,13 Then we apply centralized reactive power control method to mitigate the over voltage as shown in (Fig.4).

Table 4: The node voltage at adding two PV systems at buses (6,13)



bus .no	with out pv	12 MW at bus 13,6	after Q
1	1	1	1
2	0.9966	1.0033	0.9885
3	0.9964	1.0035	0.9884
4	0.9941	1.0051	0.9869
5	0.9939	1.0079	0.9882
6	0.9937	1.0151	0.9918
7	0.9922	1.0033	0.985
8	0.9905	1.0016	0.9833
9	0.9894	1.0006	0.9822
10	0.9889	1.0001	0.9817
11	0.9879	0.999	0.9807
12	0.9955	1.0165	0.9898
13	0.9948	1.0313	0.9975
14	0.9941	1.0306	0.9967
15	0.994	1.0305	0.9966

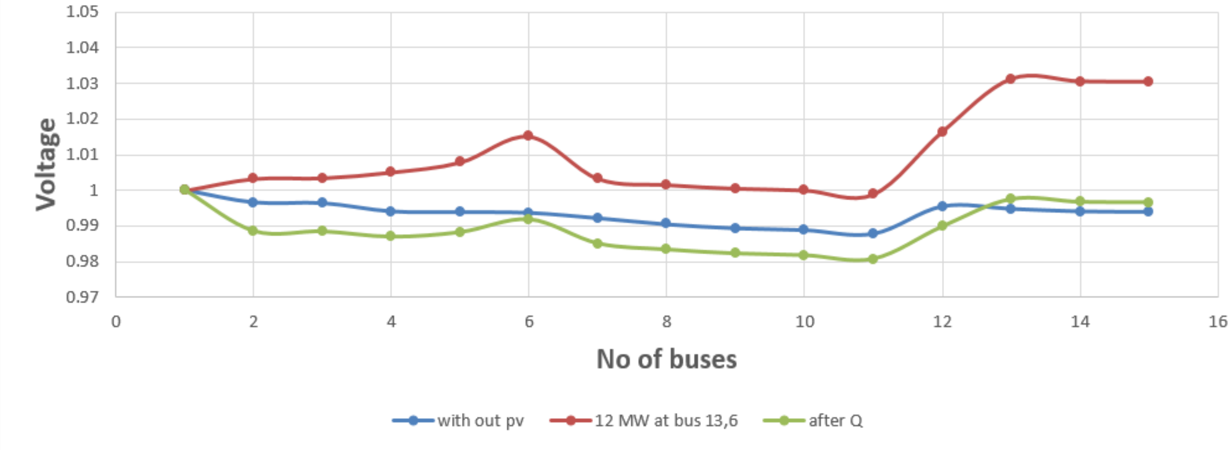
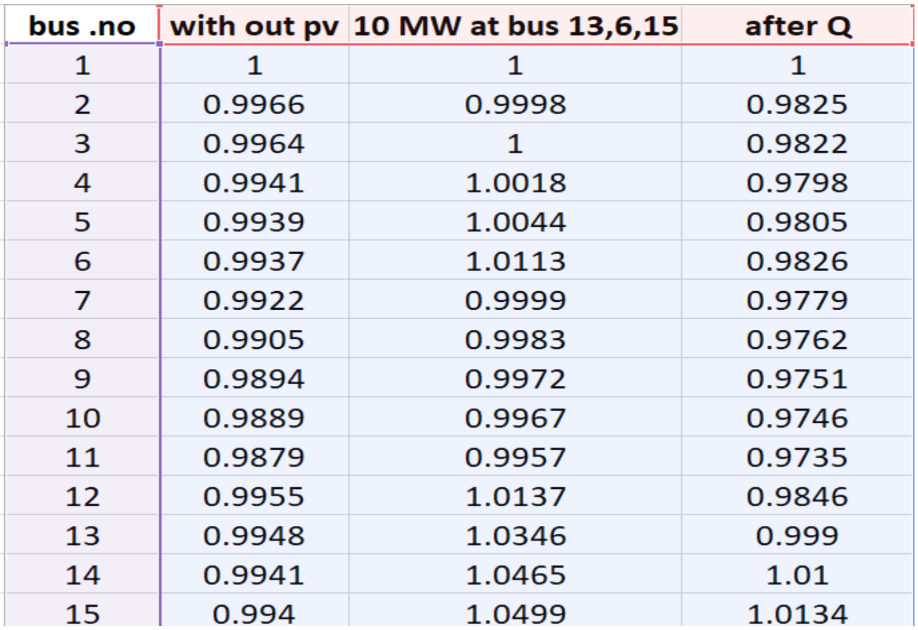


Fig 4: The voltage profile after adding two PV systems at buses (6,13)

3) Senario 3: after adding three PV systems each pv =10MW at buses (6,13,15).

In this case three PV systems with rating of 10 MW are added at bus (6,13 and 15) ,leading to overvoltage overall the system especially at buses 6,13 and 15. Then we apply centralized reactive power control method to mitigate the over voltage as shown in (Fig.5).

Table 5: The node voltage at adding three PV systems at buses (6,13,15)



bus .no	with out pv	10 MW at bus 13,6,15	after Q
1	1	1	1
2	0.9966	0.9998	0.9825
3	0.9964	1	0.9822
4	0.9941	1.0018	0.9798
5	0.9939	1.0044	0.9805
6	0.9937	1.0113	0.9826
7	0.9922	0.9999	0.9779
8	0.9905	0.9983	0.9762
9	0.9894	0.9972	0.9751
10	0.9889	0.9967	0.9746
11	0.9879	0.9957	0.9735
12	0.9955	1.0137	0.9846
13	0.9948	1.0346	0.999
14	0.9941	1.0465	1.01
15	0.994	1.0499	1.0134

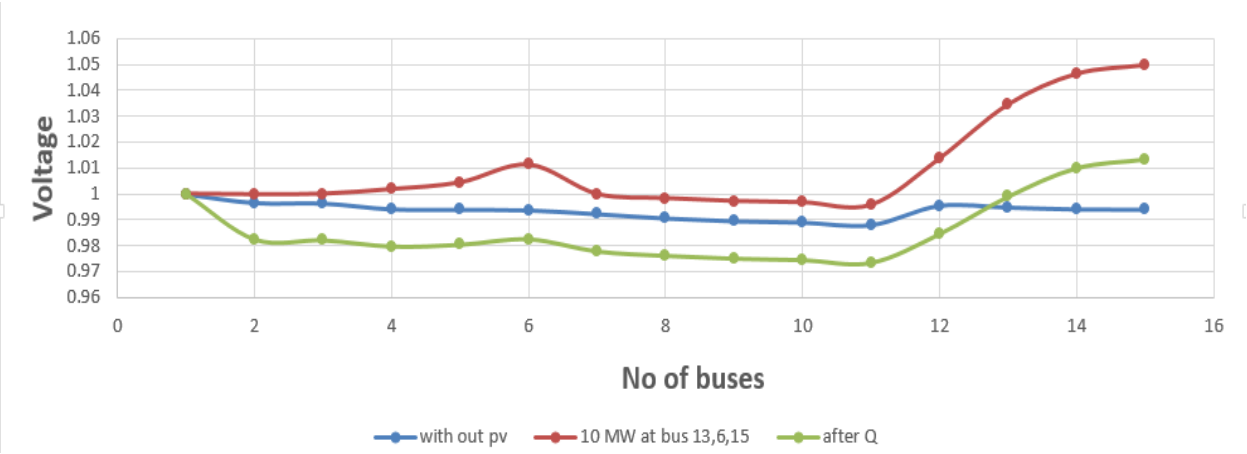


Fig 5: The voltage profile after adding two PV systems at buses (6,13,15)

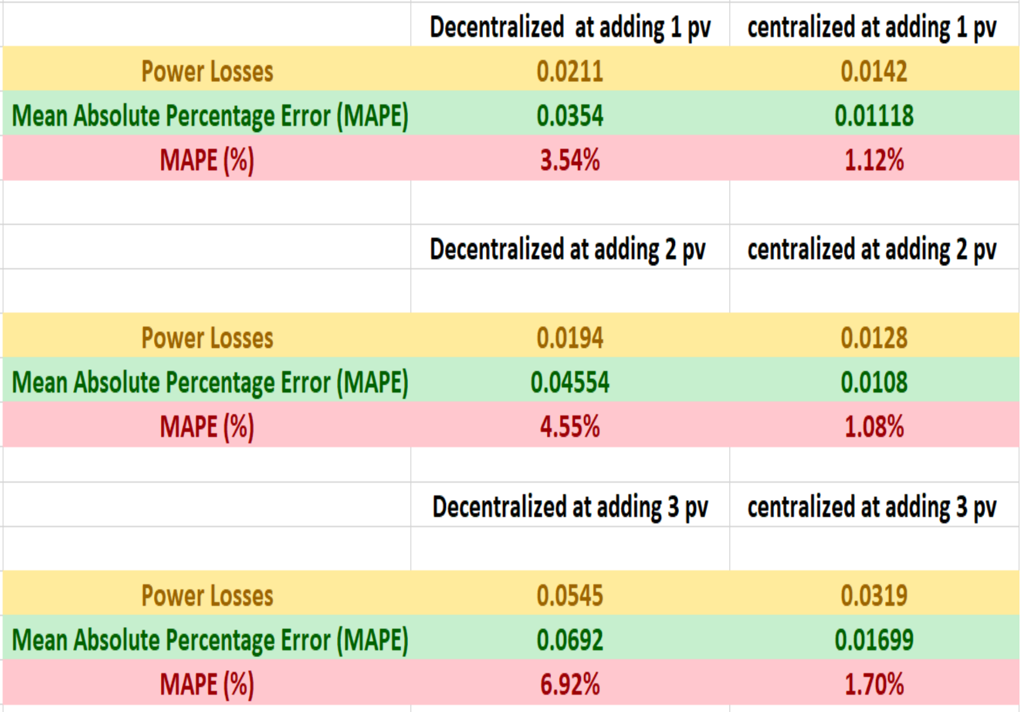
B. Comparison between decentralized case and centralized case results

In this section maximum mean absolute percentage error (MAPE) and power losses will compared in two cases: decentralized case and centralized case where the mathematical equation for MAPE is shown as:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\frac{A_t - F_t}{A_t}$$

Where A_t is the nominal voltage, F_t is the bus voltage and n is the number of buses.

Table 6: Comparison between decentralized case and centralized case results.



	Decentralized at adding 1 pv	centralized at adding 1 pv
Power Losses	0.0211	0.0142
Mean Absolute Percentage Error (MAPE)	0.0354	0.01118
MAPE (%)	3.54%	1.12%
	Decentralized at adding 2 pv	centralized at adding 2 pv
Power Losses	0.0194	0.0128
Mean Absolute Percentage Error (MAPE)	0.04554	0.0108
MAPE (%)	4.55%	1.08%
	Decentralized at adding 3 pv	centralized at adding 3 pv
Power Losses	0.0545	0.0319
Mean Absolute Percentage Error (MAPE)	0.0692	0.01699
MAPE (%)	6.92%	1.70%

As shown in (TABLE.6) that maximum mean absolute percentage error (MAPE) =6.92% in decentralized case after adding three PV system while maximum MAPE =1.70% in centralized case, maximum MAPE =4.55% in decentralized case after adding two PV system while maximum MAPE =1.08% in centralized case, and that maximum MAPE =3.54% in decentralized case after adding one PV system while maximum MAPE =1.12% in centralized case. As a result this mean that centralized control methods make the voltage profile flatten and reduce the system losses more than decentralized control method.

VI. CONCLUSION

Voltages increase on both the nodes of integration and certain nearby nodes as a result of the addition of renewable energy sources to distribution systems. The IEEE standard for integrating renewable energy is being broken by this overvoltage scenario, which needs to be corrected. Reactive power control of distribution units with inverter interfaces is a very effective solution to the described issue. In order to improve coordination across the connected PV systems, the article developed a centralised way to govern the reactive power injections which will lead to higher performance and increased efficiency. The proposed method depends on GA to determine the most suitable reactive injections from each inverter to flatten the voltage profile while reducing the system losses. It has been demonstrated that the suggested method for effectively adjusting photovoltaic units' reactive power in accordance with the feeder voltage profile's real-time scenario is a reliable method for controlling voltage. Voltage rise problems brought on by power injections at random nodes are successfully eliminated by the suggested technique. We have demonstrated through simulations that the voltage profile can be improved and the power network can become more stable when using our suggested volt/VAR optimization technique through Differential Evolution. The result reveals that maximum mean absolute percentage error (MAPE) in decentralized case more than maximum MAPE in centralized case, and power losses in centralized less than decentralized case. This implies that centralised control techniques flatten the voltage profile and reduce system losses more so than decentralised techniques. The central methods have smaller losses than the local strategies because they make greater use of reactive power.

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