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Coordinated control of Distributed Generators and Compensator in a Microgrid

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Abstract: ***The main purpose of this paper is to improve the coordination among the Distributed Generators (DGs) and Distribution STATic COMpensator (DSTATCOM) in a microgrid. When more number of DGs connected in parallel to supply the load demand, the key issue rises is about the power quality (PQ) a problem like reactive power mismatch. So, the intention of this paper is to boost the PQ by placing a DSTATCOM with a new control methodology. The proposed reactive power compensation (RPC) control strategy is based on the voltage drop and power flow. The simulations of the system with DSTATCOM substantiate the best outcomes compared to the conventional control methods.***

Index Terms: Microgrid, DSTATCOM, Distributed Generators (DG), Voltage Source Inverter (VSI), Reactive Power.

I. INTRODUCTION

The world is moving towards green power as the conventional fuels are diminishing rapidly. Power converters are very essential in the current scenario to convert power from DC to AC and because of this many power quality issues are becoming pressing challenges in the micro grid. These issues can be solved by using eco-friendly power sources and hence the benefits of distribution generation are getting aware everywhere [1], [2]. Deployment of DGs to enhance a microgrid performance is valuable for the users and also for the control agencies which are in close proximity to the power generation [3]. Microgrid concept was proposed to organize various natural power sources into distribution systems (both in grid-connected operation and in islanding operations) in an smart way [4], [5].DGs are connected in parallel to obtain substantial amount of power with more reliability & efficiency. Whenever two DGs connected in parallel transfers power to the loads through various feeder impedances, the active and reactive powers are not spread uniformly in load. A few strategies are proposed to address this challenge [6-8]. Compensators play a vital role in changing the scenario towards stability. The best possibility is to manage appropriately the distributed generators and the compensating devices. In the current micro-grid, controlling the PQ challenges is attained by using power electronic converters [9].

In a current situation distribution system's more power is utilized for reactive loads, for example, fans, motors, pumps etc. These loads require lagging power factor and in this way offer rise to RP hitch in the distribution network. For RPC, distribution static synchronous compensator gives RP as required by the load and the source current gives unity power factor [10]. Distribution static compensator (DSTATCOM) is a swift and fast operated controller and provides the necessary voltage support and PQ enhancement and besides it gives a traverse through capacity aimed transients to microgrid [11]. In any case, Active Power (AP) and RP in a low-voltage system are more critical and path of voltage has to to consider the flow of AP and RP [12]. A DSTATCOM is developed for either bus voltage or line current compensation [13]. In microgrid, the distributed generators work with voltage control and to achieve RPC with the distributed generators, it is preferable to use the DSTATCOM for voltage stability.The main apprehension of this paper to make certain the reactive power compensation with appropriate synchronization among the DGs and DSTATCOM. The proposed control technique ensures rapid RPC within the voltage regulation limit based on the flow of power. The results clearly indicate that reactive power compensation can be attained using the proposed control strategy.

II. LITERATURE REVIEW

The control and operation of 1-Φ micro-sources (converter based singe-phase DGs) in a utility connected grid is proposed by R. Majumder, et al. (2009) [14]. The solution for the problem of voltage profile present in 1-Φ system is addressed using two different methods. The first strategy is DSTATCOM associated at the utility bus to improve the PQ. The second strategy is to place the 3-Φ converter controlled distributed generator at the point of common coupling to distribute the AP & RP, with utility and to compensate for the unequal and non-linearities in the framework.

The stability issue of the grid connected VSI with LC channels is dissected in the paper Y.Shuitao, et al. (2011) [15]. The grid impedance strongly affects VSCs, so the control of the distributed generators should be changed dependent on framework linked or islanded method of the microgrid. A H∞ controller with express robustness as far as grid impedance variety is proposed to consolidate the ideal tracking execution and security edge. These controllers can be effectively connected to the 1-Φ grid associated inverter also. In this paper, the determination of weighting capacities, inward inverter-yield current circle structure and framework unsettling influence dismissal ability are as well discussed. J. M. Guerrero, et al. (2009) [16], deals with the control methodology for adaptable micro-grid.

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In the proposed micro-grid, a parallel operation of a few line-intelligent uninterruptable power supply framework is illustrated. Many authors discussed about the reactive power compensation based on multiple parameters like type of compensators, control strategies and events that frequently happen in the micro grid [17-21].

III. MICROGRID CONFIGURATION

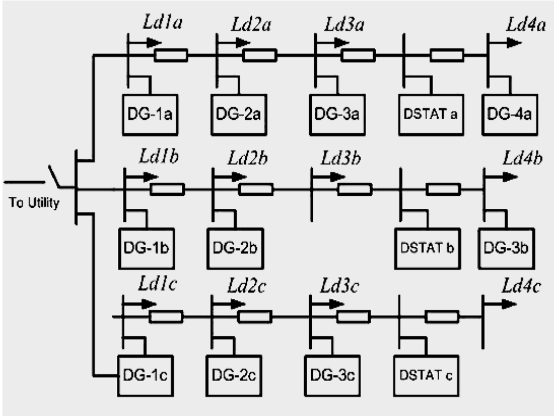
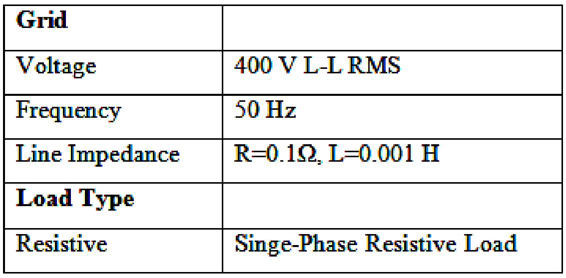


Figure.1 Microgrid structure [17]

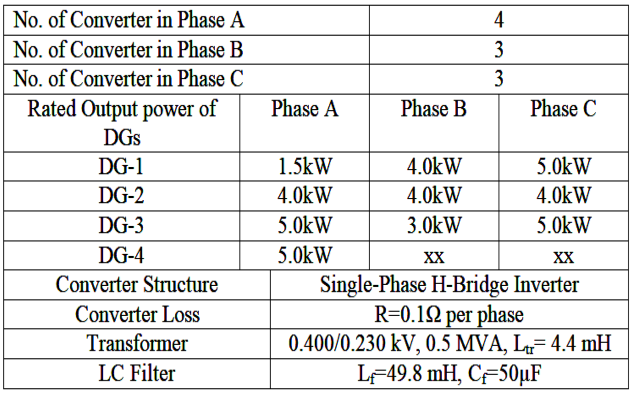
The structure of microgrid under consideration is shown in the figure.1 with three feeder segments, four DGs and one DSTATCOM in phase-A, three DGs and one DSTATCOM in phase-B and three DGs and one DSTATCOM in phase-C. Four loads are connected in each phase. The locations of the DSTATCOMs are chosen far from the utility end and they are indicated as DSTATa, DSTATb and DSTATc. The specifications considered for the modeling and simulation are tabulated in Table-1.

Table-I Grid Parameters



Grid	
Voltage	400 V L-L RMS
Frequency	50 Hz
Line Impedance	R=0.1Ω, L=0.001 H
Load Type	
Resistive	Singe-Phase Resistive Load

Table-II Converter and Controller Parameters

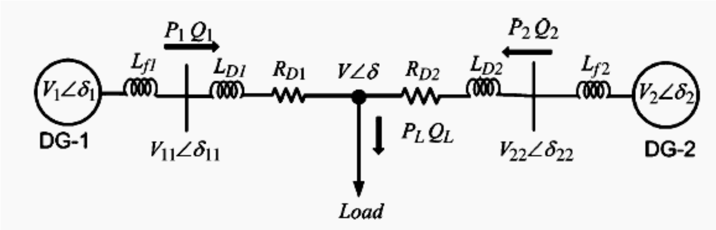


No. of Converter in Phase A	4		
No. of Converter in Phase B	3		
No. of Converter in Phase C	3		
Rated Output power of DGs	Phase A	Phase B	Phase C
DG-1	1.5kW	4.0kW	5.0kW
DG-2	4.0kW	4.0kW	4.0kW
DG-3	5.0kW	3.0kW	5.0kW
DG-4	5.0kW	xx	xx
Converter Structure	Single-Phase H-Bridge Inverter		
Converter Loss	R=0.1Ω per phase		
Transformer	0.400/0.230 kV, 0.5 MVA, L_{tr}= 4.4 mH		
LC Filter	L_f=49.8 mH, C_f=50μF		

Figure.2 Two machine system [12].

IV. PROPOSED POWER FLOW CONTROL OF DG AND DSTATCOM

The coordinated control of the DGs and distribution static synchronous compensator is explained in this section. The basic intention of RPC is based on the power flow and voltage variation in line. To attain the voltage regulation, it is better to consider the flow of power in the distribution static synchronous compensator control.



Initially a two machine sample is shown in the figure.2 to understand the active power and RP relations. Finally Multi-machine system is considered for RPC. These samples are discussed to familiarize the concept of DGs and DSTATCOM control.

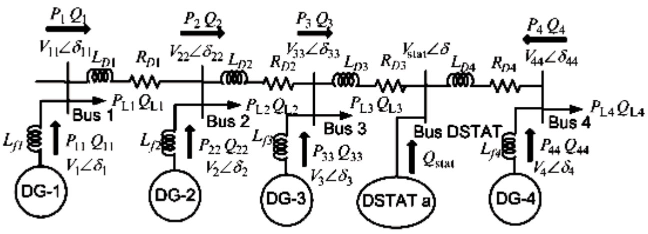


Figure.3 Multi machine system [17].

The reference voltage and current generated for providing the reactive power compensation is expressed in [17]. If the RP demand increases, reference voltage can be varied by changing the RP at the output till the maximum available RP limit of the DG. When the DGs touch the RP limit and the voltage profile comes down the voltage regulation limit, i.e., still further more RP requirement is required; the corresponding RP is generated by the DSTATCOM.

Power flow of two machine system [17] can be written as

$$P_1 = \eta[R_{D1} (V_{11} – VCos(\delta_{11} - \delta) + X_{D1}VSin(\delta_{11} - \delta)] \quad …….. (1)$$

$$Q_1 = \eta[-R_{D1} VSin(\delta_{11} - \delta) + X_{D1} (V_{11} – VCos(\delta_{11} - \delta)] \quad …….. (2)$$

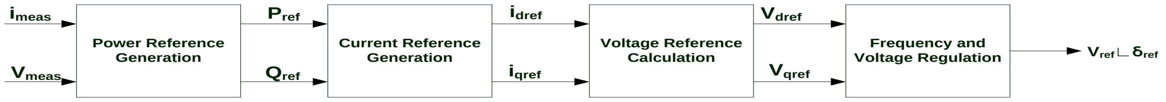


Figure.4 Converter control of DG.

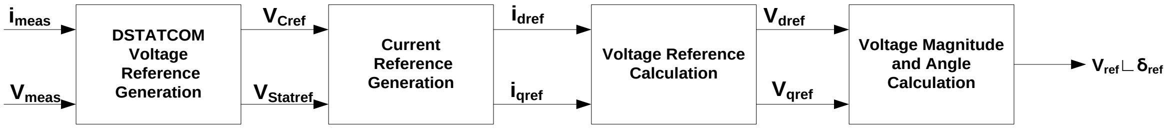


Figure.5 Converter control of DSTATCOM

The reference voltage of the DSTATCOM for the multi-machine system [17] is shown.

$$V_{statref} = V_0 - m_{STAT} Q_{STAT} + K_1 \frac{R_{D_1} P_1 + X_{D_1} Q_1}{V_{11} V_{22}} + K_2 \frac{R_{D_2} P_2 + X_{D_2} Q_2}{V_{22} V_{33}} + K_3 \frac{R_{D_3} P_3 + X_{D_3} Q_3}{V_{33} V_{stat}} + K_4 \frac{R_{D_4} P_4 + X_{D_4} Q_4}{V_{44} V_{stat}} \quad \ldots\ldots. (3)$$

It is esteemed that in case-1 the voltage dip is high in the far end (FE) of the feeder and DGs at the FE are highly probable to attain the reactive current limit. In case-2 voltage in all locations can come down to the required voltage regulation limit. With the help of distribution static synchronous compensator, the distributed generators far from distribution static synchronous compensator may attain its RP limit, while distributed generators near the distribution static synchronous compensator will operate in proportional reactive slop under the limit. The RP generated by distribution static synchronous compensator will enhance the voltage at distribution static synchronous compensator bus and also voltage in busses adjacent to that.

V. STRUCTURE OF DISTRIBUTED GENERATORS

Converters information is mentioned in Table II. Figure. 4 represent the converter control scheme for DG-1. The frequency and voltage reference generation and the current control loop are appeared in Figure. 4.Figure.5 represents the converter control scheme for distribution static synchronous compensator. The distribution static synchronous compensator o/p voltage reference $V_{statref}$ is determined by the equation (3). The DC voltage is hold on to a settled esteem Vcref. The ref current generation is appeared in Figure. 5. The error in DC capacitor voltage is given through a PI controller to get the d-axis current ref, while the error in distribution static synchronous compensator o/p voltage is utilized to generate the q-axis current ref. In [17], the control strategies for DGs and DSTATCOM are explained. It very well may be seen that in case-1, the DG gives max accessible power. The frequency and voltage controls with droop are enacted in case-2. If the distributed generator comes to RP limit, the AP ref is adjusted.The distributed generator converter structure and control scheme are comparative. Figure.6 is the representation of converter structure for DG-1. The 1-Φ converter is made of 4 IGBTs and the converter AC side o/p voltage is associated through the transformer to the o/p filter capacitor (C_f) is shown in Figure.6. Inductance and transformer loss are expressed by L_{tr} and R_{tr}, resp. The distributed generator is associated with the PCC through o/p inductance (L_f).

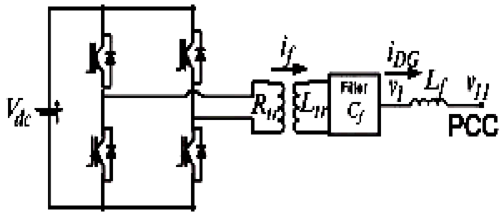


Figure.6 Converter structure of DG-1 [17]

In case-1, by Voltage Reference Calculation block the voltage reference is determined and is specifically fed to the converters. The generation of active and RP dependent on converter current limit and it is to be noticed that the frequency and voltage control is just operates in case-2 activity. The voltage magnitude is maintained by RP, where the voltage angle controlled by the AP o/p [18].

VI. CONVERTOR STRUCTURE OF DSTATCOM

Figure.7 is a converter structure of the distribution static synchronous compensator. H-bridge is connected with the capacitor in the DC side and the AC side voltage e_{stat} is connected through the transformer to o/p filter capacitor. The distribution static synchronous compensator o/p current and voltage is appeared as v_{stat} & i_{STAT}, resp.

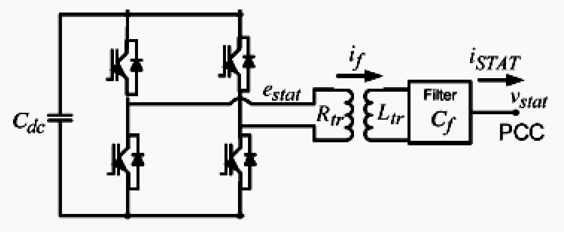


Figure.7 Converter circuit of DSTATCOM [17]

The converter of DSTATCOM is controlled using the instantaneous power theory, for the generation of voltage reference and the phase angle.

VII. SIMULATION OF POWER NETWORK USING MATLAB

The system appeared in Figure. 1 is simulated for various test cases as follows

Scenario 1: No RPC.
Scenario 2: RPC on local measurements.
Scenario 3: RPC with novel technique.

To compare the controller execution for each scenario, comparable arrangement of varying in distributed generator power o/p and the load switching case is contemplated. There are 3 various cases of situations considered to examine the efficiency of the proposed strategy. Those are; case-1, case-2, and case-3 respectively.

Case-1: Grid-connected.

Case-2: Autonomous mode.

Case-3: Grid-connected followed by autonomous mode.

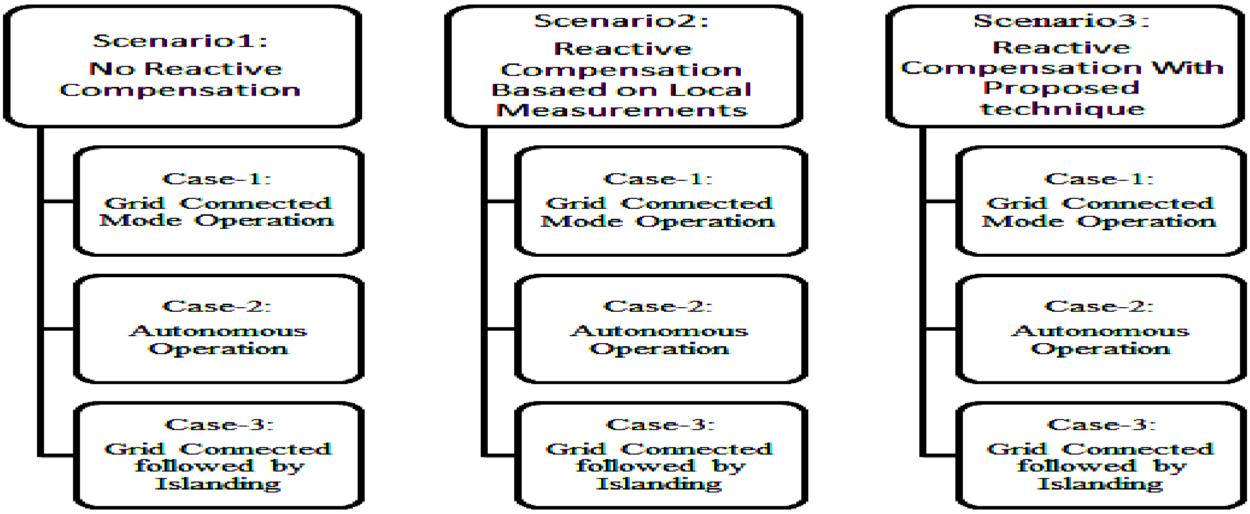


Figure.8 Various Test Cases.

The explanation of each case is given below

Case-1: It is concluded that framework is working in grid-connected mode. While the framework is under steady state, with all the distributed generators providing limited power and all loads are connected, o/p powers of 3 distributed generators connected to phase-a, (DG-1_a, DG-2_a & DG-3_a) are constrained to 2000 W each. The RP are likewise restricted to 300 VAr [17]. Case-2: It is concluded that framework is working in islanded mode. While the framework is under steady state with all the DGs providing limited power and all loads are connected, o/p powers of 3 distributed generators connected to Bus-2 of each of the 3 phases (DG a_2, DGb_2 & DG c_2) are constrained to 2000 W each. The RP are also constrained to 400 VAr [17]. Case-3: It is concluded that framework is working in utility-connected mode. While the framework is under steady state with all the DGs providing limited power and all loads are connected, the microgrid is islanded at 0.8 s and the distributed generators supply load demand. At 1.1 s, o/p powers of distributed generators (DG-2_a, DG-2_b, & DG-2_c) are limited to 2000 W. To diminish the power request in the microgrid, at 2.0 s, loads are connected at Bus-1 of phase-A & phase-B (L_d1a & L_d1b) are removed [17].

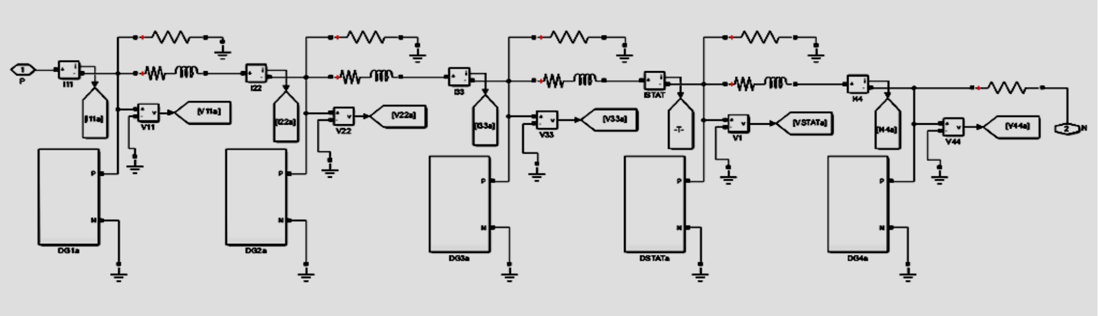


Figure.9 Simulation structure of multi-machine system.

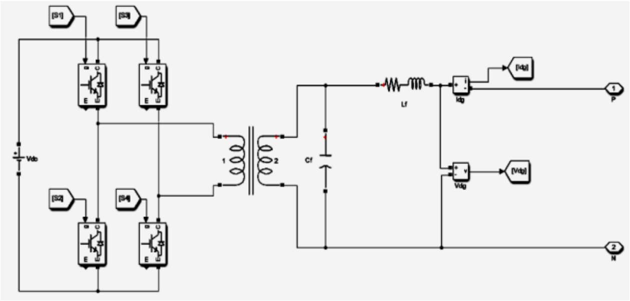


Figure.10 Simulation structure of DG.

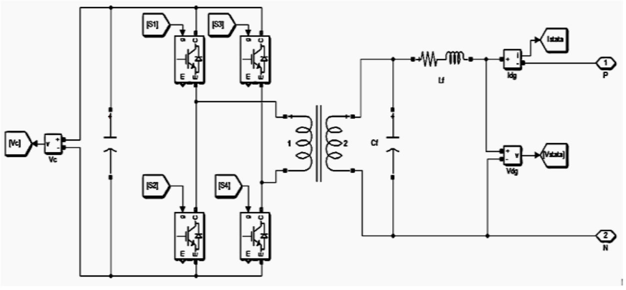


Figure.11 Simulation structure of DSTATCOM.

VIII. RESULTS AND DISCUSSION

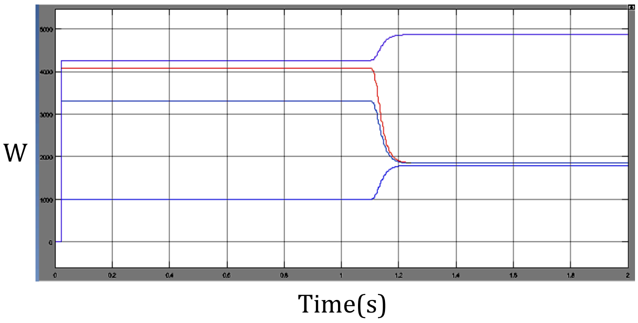


Figure.12 Power Output in phase-A (DGs)

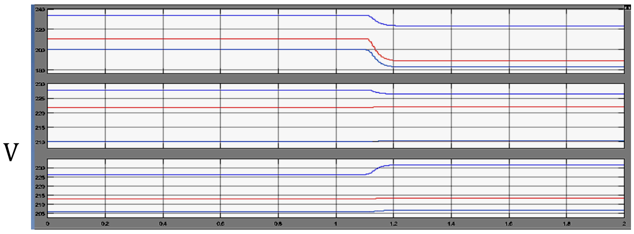
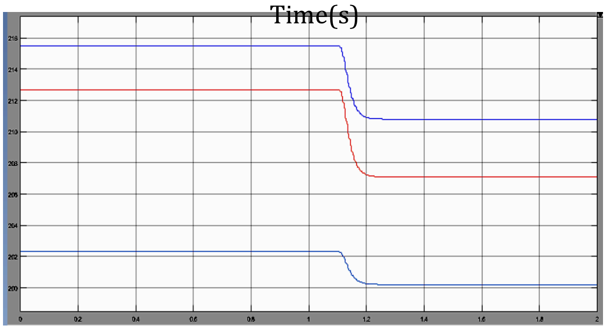
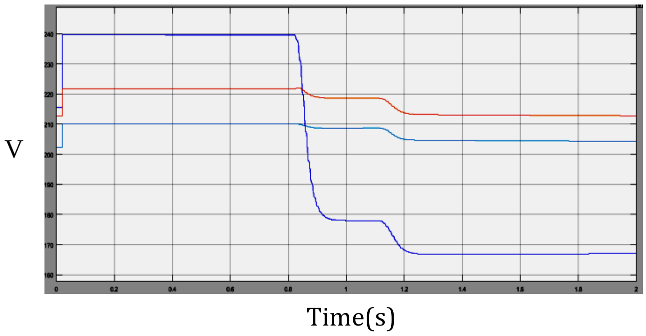


Figure.13 RMS voltage in three phases.



(a)



(b)

Figure.14.RMS voltages in (a) Case-2 (phase-A).
(b) Case-3 (phase-B).

In each scenario, different casas as portrayed above are utilized. In Figure.8 the various test cases are appeared. The simulation outputs for each scenario are represented below.

Scenario-1: No RPC (Reactive power compensation)

In scenario-1, no RPC is considered and the total RP is provided by the distributed generators and utility (in case-1) or just by the distributed generators (DGs) (in case-2). For case-1, the power o/p of the distributed generators connected to phase-A is appeared in Figure.12, where the voltage profile in 3 phases is appeared in Figure. 13. It tends to be seen that voltage regulation issue is more in the middle of the feeders (MF) and far end of the feeder (FE). The voltage dip at the utility-connected side (Ut.S) stays under 2%.

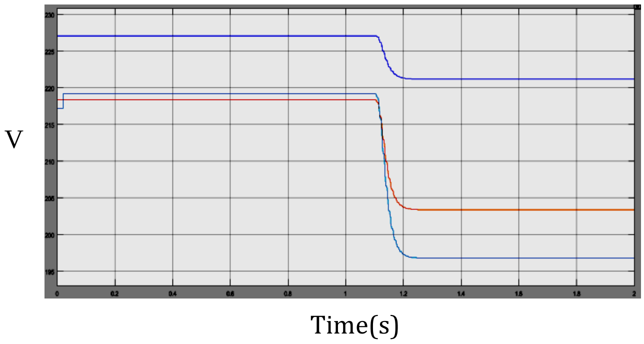
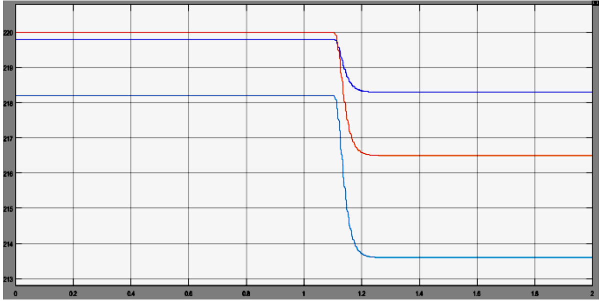


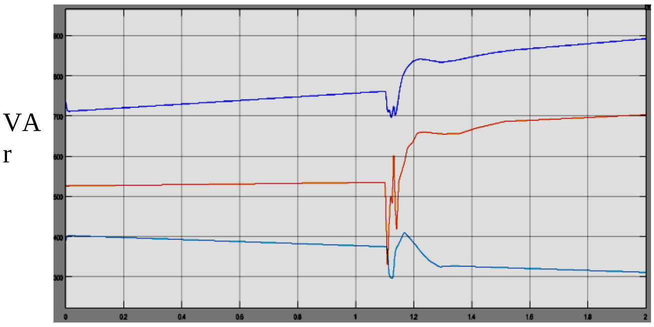
Figure.15 RMS voltage in Case-1(phase A) with DSTATCOM.

The RMS voltage and voltage variations in case-2 and case-3 are appeared in Figure. 14. It tends to be seen that the voltage regulation issues exist and the voltage dip more than the adequate values.



(a)

Time(s)



(b)

Figure.16 (a) RMS voltage in various location.
(b) RP injected in 3 phases.

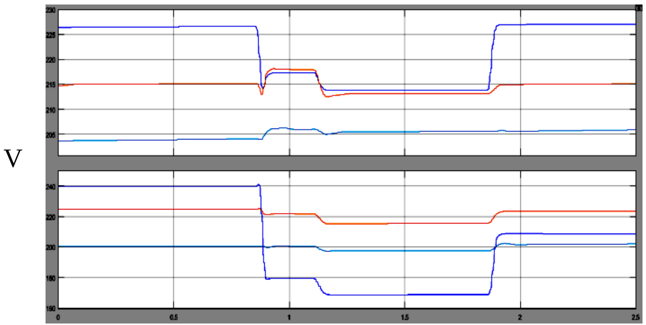
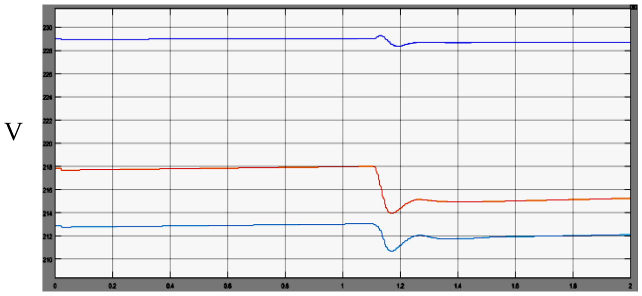


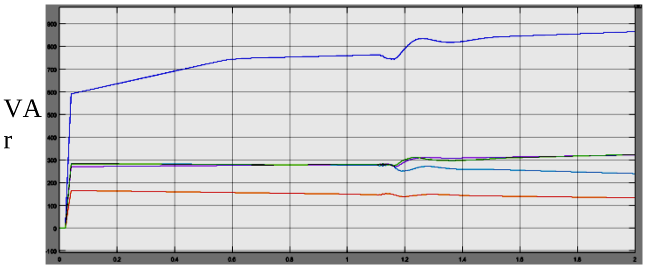
Figure.17 RMS voltages in (a) Case-3 (phase-A). (b) Case-3 (phase-B).

Scenario-2: RPC on Local operation.

In scenario-2, the DSTATCOM operates routinely. The RP injection depends on the local bus voltage of the distribution static compensator. Figure. 15 represents the RMS voltage of case-1. The RP injections by DSTATCOM and the RMS voltages in case-2 & case-3 are appeared in Figures.16 & 17 resp. It tends to be seen that the voltage profile is enhanced contrasted with this scenario where no RPC is utilized. In any case, the voltages are beneath limit in a few scenarios and the reactive power compensation functions admirably just near the DSTATCOM.



(a)



(b)

Figure.18 (a) RMS voltages in Case-1 with scenario-3; (b) RP injection of the DSTATCOM and DGs.

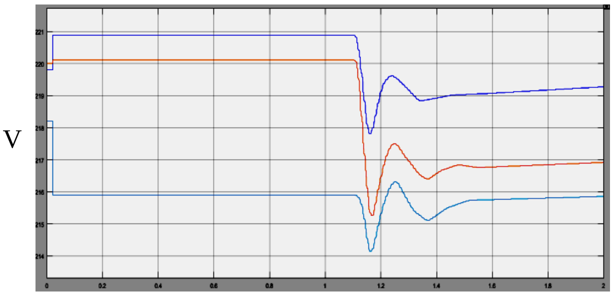
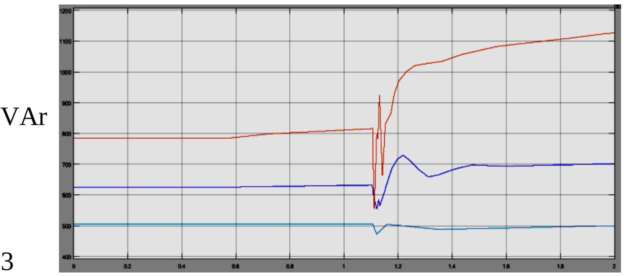


Figure.19 (a) RMS voltages in Case-2.

(b) Reactive power injection of DSTATCOM

(a)



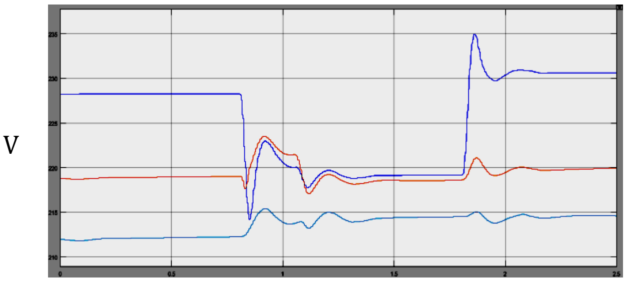


Figure.20 RMS voltages in Case-3 (Phase-A).

Scenario-3: RPC with Proposed Technique.

In scenario-3, the RPC is accomplished with proposed technique specified by (3).Figure.18 (a) represents the RMS voltages in case-1 (phase-A). It tends to be seen that with the proposed technique, the voltage profile enhances (fewer than 10% tolerance). Figure.18 (b) demonstrates the RP injection by the DSTAT-a and distributed generator connected to phase-A. In Figure.19 the system response in case-2 with the proposed controller is appeared. The RP injection from various distribution static compensator and phase-A voltage demonstrates stable and effective system operation. In Figure.20 the voltage in case-3 (phase-A) are appeared. The compensation is accomplished by the proposed strategy and the voltages are kept under the acceptable limit.

IX. CONCLUSION

This paper simulates a novel control mechanism for DSTATCOM in a 1- Φ microgrid, to control the energy compensation. This scheme is aimed for microgrid feeding 1-Φ load with feeder’s geographically separated covering mini networks. The proposed RPC is based on nearby voltage estimation and the flow of power in lines. It is concluded that proposed strategy reduces the voltage drop more viably while managing the voltage control by much penetration of the distributed generators (DGs). The MATLAB simulations of the considered framework with the proposed DSTATCOM exhibits the best results compared to the other existing methods stated here in this paper. The future scope of developing a new model based on the communication networking is under research and the impacts will be studied to empower the quality of power.

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