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MODIFIED DECENTRALIZE CONTROL STRATEGY FOR ACCURATE REACTIVE POWER SHARING IN ISLANDED MICROGRID

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Abstract
The primary function of a microgrid (MG) is proper power sharing as per load demand if multiple DG units are used. Conventionally, the droop control topology for accurate power sharing is used. However, it has some power control stability issues. The sharing of active power at the steady state level is accurate while the sharing of reactive power is affected by impedances of mismatched feeders. Many methods have been presented to share the reactive power equally. But these suffer from some functional difficulties. The usage of communication links makes correction process of Q-V droop curve slow and inappropriate which ultimately fluctuate the output of DGs. In this work, a local reactive power correction scheme has been proposed for an inverter-based MG to resolve these issues. The correction process has been triggered by monitoring the significant DG switching, load changes and mode transfer of the microgrid. Transient reactive power has been injected in P-ω droop curve to generate disturbance in active power. It helps to compute the reactive power sharing error which will be corrected with the help of PI controller. PI controller modifies the value of the slope and y-intercept of the conventional Q-V droop control method. The proposed technique accurately shares the reactive power and makes the network more stable and reliable as compared to the communication-based methods.

Keywords: Decentralized control; distributed generation (DG); droop control method; microgrid control; power sharing.

I. INTRODUCTION

Now a days, one of the dominating strategies, is to enhance the usage of renewable energy resources e.g. solar, wind etc. to cope with the issues of increased carbon emissions and more electricity demands. Subsequently, the current grid structure is moving to the decentralization. The microgrid structure is a promising solution to overcome the stress on the current power transmission systems by the interconnection of different types of distributed generation units. Microgrid has the ability to operate in two different modes, islanded and grid connected. The islanded configuration has some challenging power control issues [1].

When a MG is functioning in an islanded mode, the load should be properly shared among different types of DGs according to their proportion. The conventional droop control techniques have been adopted for the accurate sharing of the reactive and active powers. The main benefit of the droop control method is its independency on the intercommunication interfaces among the different types of the DGs. Although, the P-ω droop control method accurately shared the active power among DG units while the Q-V droop method has some power control stability issues due to following reasons:

1. Voltage of the DG unit is a local parameter.
2. Unlike the active power, the reactive power is associated with the network topology and the line impedances as well [2].
3. Local Loads in most of the DGs affect the accuracy of the reactive power sharing.
4. In a LVMG, the nature of the line impedances

is mostly resistive. Hence, the coupling amid the real and reactive power is unavoidable [3].

Inaccurate reactive power sharing in an islanded MG produces frequency and voltage fluctuations and poor power quality issues which can affects the stability of a microgrid. DGs output fluctuations can also produce severe economic losses. Hence, the correction of Q-V droop control methods have acquired a ton of interest.

To cover up the issues of reactive power sharing, different improved droop control techniques have been proposed. In [4], the improved droop technique has been developed which calculates the differences among the local and the common bus voltage. The difference is compensated by the integration term which was injected at the outcome of Q-V droop icon. But this improved methodology requires accessing the common bus which is not a practicable way. Another technique has been proposed which uses the real time data of the voltage drops and local loads to calculate the accurate reactive-voltage droop parameter. However, this technique is not affordable because of the requirement of real time data [5].

Golshan[6] increased the slop of the conventional droop method in heavy loading condition. But this method has a drawback of bad voltage profile during the condition of heavy loads. This issue is resolved by the optimization method. However, this technique is very complicated because it needs the all information of the network configuration.

Another virtual impedance-based method has been developed in [7] for appropriate reactive power sharing. The technique is desired to compensate the output impedances of the DGs. However, this topology needs a controller that estimate the virtual voltage drops among the output impedances which is not a practical way in the real world [8]. When the real time data is not available, virtual impedance-based methods cannot accurately share the power as needed [9].

Another technique is presented in [10] to mitigate the errors of Q-V droop curves. This topology corrects the gains of droop control in accordance with the changes in DG units operating points.

In [11] & [12] an enhanced scheme of reactive power sharing has been presented. This strategy calculates the reactive power sharing errors by adding the very little disturbance of real power. The scheme is started by low bandwidth synchronization communication. This correction scheme activation signal is transferred from the secondary controller. Integral term is utilized for the correction of errors. The technique is implemented in two stages. In the first stage, conventional droop control topology is utilized. In next step, the active power disturbance is added. This topology is not very sensitive to the impedance, mismatch that's why it is a very famous technique among the researchers.

The techniques presented are very popular among the researchers because they do not need any type of complex central controllers and large investment cost. However, they have some practical issues:

1. Firstly, utilizing the communication signals, diminish the reliability of the arrangement. Any spontaneous delay or failure in the information transmission, drops the execution of the proposed strategies.
2. Secondly, the correction scheme of the droop control method is slow and inaccurate to produce fluctuations across the DG units. This problem disturbs the working of the microgrid under few operational situations, particularly when there is a perceptible variations in the load or the system methodology [10], [11] & [12].

In this work, a new technique has been presented to enhance the reactive power sharing between different DGs without using any communication link.

This research paper is arranged as follows: Modeling of the system is depicted in Section I. Section II presents the methodology of the proposed method. Section III & IV presents the results & discussion and conclusion respectively.

2. MODELING OF THE SYSTEM

Fig.1 shows the schematic of a microgrid. The MG is made up of 3 DG units, 6 switches and 4 linear loads. Inverters are utilized for the interfacing of the DG units with the MG. The inverters are interfaced with the common ac bus through their particular feeder impedances. LC filter is connected between the output of the IGBT Bridge and the feeders. Values of LC filter are presented in Table1. The differences in the output impedances of the DGs increase the inaccuracy of reactive power sharing. To make this network asymmetrical, local load are also added at the 1st DG unit.

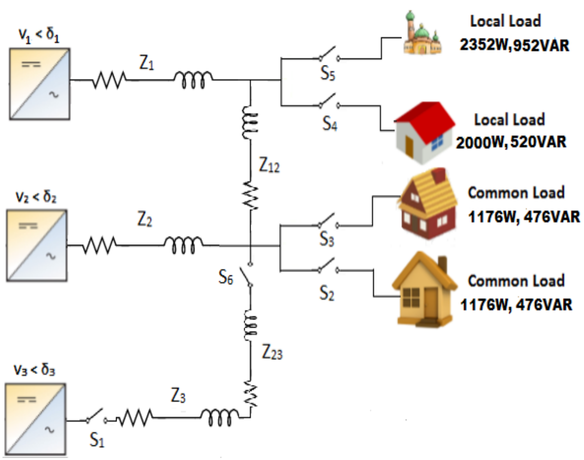


Fig. 1. Test System of the MG

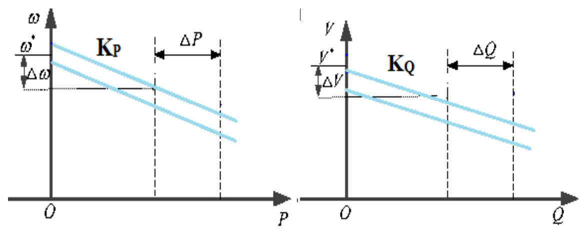
Table 1: Parameters of MG

Parameters	Values	
Inverter & Microgrid	Nominal Voltage	120V
	DC offset Voltage	400V
	DG ratings	DG1= DG2=DG3=6KVA
	Inverter Filters parameters	L=6 mH, C=40μF
	Sampling Period	$5*10^{-6}$ s
	Feeder Impedances	Z1=Z2=Z3=0.2+J1.141Ω Z12=Z23=0.3+J0.754Ω
Coefficients of Controllers	Droop Coefficient of Frequency	DP1=DP2=DP3=0.00124 Rad/(Sec.W)
	Droop Coefficient of Voltage	DQ1=DQ2=DQ3=0.00142 Rad/(Sec.W)
	Compensation Controller	Kp=0.003, Ki=0.0286
	Current Controller Gain	K=0.25
	Voltage Controller Gain	Kp=0.3, Ki=280.7

References of active and reactive powers are commonly given by the help of the central controller. Then conventional droop technique is adopted for achieving these power references. It follows the principle of the conventional synchronous generator which is further divided into two methods:

1. P-ω droop control method
2. Q-V droop control method

If the load is not properly shared among all of the DG units then the frequency and voltage of all DGs will not be similar. Hence, these two conventional droop control methods make it possible to adjust the power of all DGs proportional to their ratings. Fig. 2 (a) shows the relation between ω & P and Fig. 2 (b) shows the relation between V & Q respectively.



(a) P-ω droop control (b) Q-V droop control

Fig.2. Conventional Droop Curves

The corresponding equations of the Conventional droop control method are as follows:

$$\omega=\omega_o - K_P.P \quad (1)$$

$$V=V_o - K_Q.Q \quad (2)$$

Where K_P & K_Q show the real power and reactive power droop slops respectively. The values of K_P and K_Q are written in Eq. (3) & (4) respectively.

$$K_P = \frac{\omega_{maximum}-\omega_{minimum}}{P_{maximum}} \quad (3)$$

$$K_Q = \frac{V_{maximum}-V_{minimum}}{2Q_{maximum}} \quad (4)$$

P-ω droop control method accurately shared the active power among DG units while the reactive power is not properly shared by the Q-V droop control method [13]. To calculate the reactive power sharing error, active and reactive power coupling term is used which is written as in Eq. (5):

$$\omega=\omega_o - K_P.(D_PP+D_QQ) \quad (5)$$

If the droop coefficients $(D_P$ and $D_Q)$ are equal for all of the DG units then (D_PP+D_QQ) should also be equal for all of them.

3. METHODOLOGY

The flow chart of the synchronized reactive power correction scheme is depicted in Fig. 3. The dominant concern of this paper is to implement Local start recognition topology for the synchronized reactive power correction scheme.

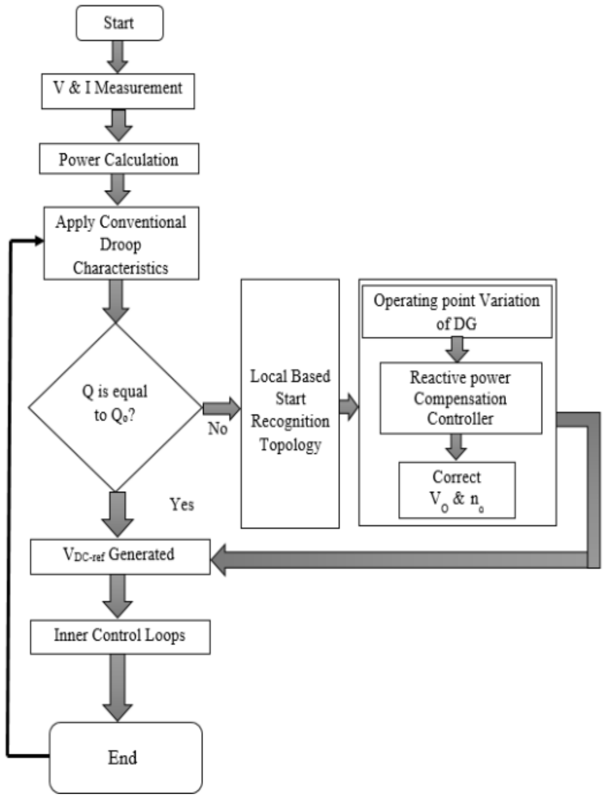


Fig. 3. Flow Chart of the synchronized reactive power correction Scheme

The proposed method for local based start recognition topology of reactive power correction technique is shown in Fig. 4. The sharing of reactive power in any MG is mostly disturbed due to the changes in operating point of the DG units. It is better to take reactive power variation as a triggering signal for the modified reactive power sharing scheme. Microscopic changes in reactive power are considered as a dc offset. Hence high pass filter is connected at the start of the correction procedure. Then the absolute magnitude of the *Q* is connected. Afterwards, the comparator compares the values of the predefined limit of reactive power and the |*dQ*|. When the system is operating at the transient state then there are some fluctuations in the reactive power. These fluctuations can be due to:

1. During the procedure of DGs startup and shutdown
2. Variations in the loads of a microgrid
3. Modes transfer of a microgrid from islanded mode to the grid connected mode and vice versa.

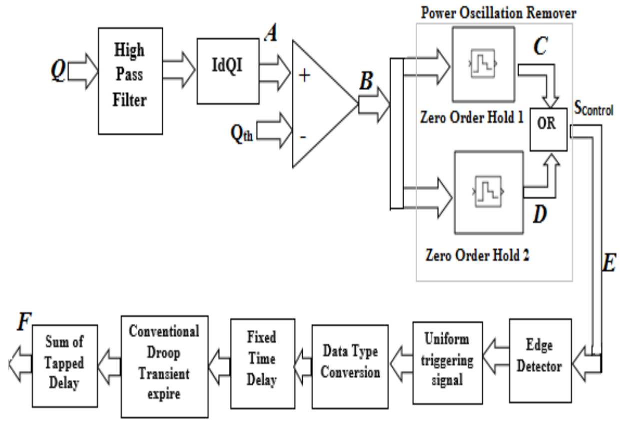


Fig. 4. Local based start recognition topology

It is important to highlight that the triggering procedure will start only one time for all the threshold crossings. These crossings might be happened amid the periods called as T_{TC}. These sampling durations are defined as per the damping speeds of the absolute magnitude of reactive power flag, that might be high for the DG switching and mode-exchange (T_{TC1}) of MG or can be low for the load variations (T_{TC2}). That's why two different zero order hold icons are connected in the power oscillation remover block. In result, they generate two different types of signals. The combination of these signals is named as $S_{Control}$. Then Edge detector block generated a uniform starting signal. After that the data type conversion block is utilized to convert the control signal into the specified type of data. After this, to terminate the transient behavior of the conventional droop a sufficient delay must be added to the procedure. When the '$S_{Control}$' is properly ready, it is used as the starting flag for the synchronized reactive power compensation scheme. Then the summation of tapped delay icon is needed for the correction of Q-V droop control.

The modified compensation strategy for reactive power sharing is executed through the two different steps:

1. At transient state MG system is following the conventional droop control method.
2. At the steady state, if Q is not equal to Q_o then the system moves towards the synchronized reactive power correction method.

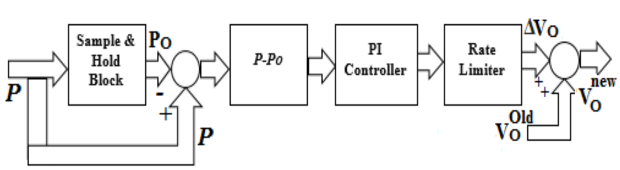
Stage 1: Conventional Droop Control Method for power sharing at initial stage:

Before the triggering signal of the reactive power compensation method, conventional droop control topology is adopted for the sharing of real and reactive powers. To compute the correct mean values of the real and reactive powers, two low pass filters are utilized here. In this stage, the steady state value of the P_O will be calculated. This value is used in the reactive power compensation method.

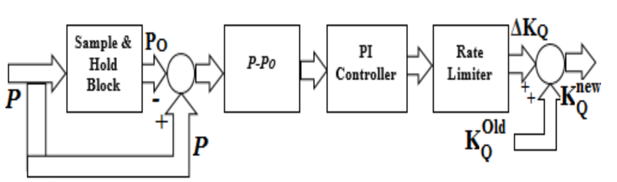
Stage 2: Synchronized Reactive Power Compensation Scheme:

This stage is activated by the local based start recognition topology. In this stage, transient reactive power is added in the system to generate disturbance in real power. The coupling among the real and reactive powers is utilized to measure the reactive power sharing error. The error is compensated by the Integral voltage term as depicted in Fig.5. Once the compensation scheme is started Eq. (1) & (3) are replaced by the Eq. (5) & (6). According to this phenomenon two general situations are made:

If the value of Q is less than Q_o in one DG unit then the value of the term $(D_P P+D_Q Q)$ will increase. According to the Eq. (5), an increment in term $(D_P P+D_Q Q - \omega_o)$ increase the frequency which ultimately decreases the P. This change in active power from P_O to P will be used as the correction method for the slop and y-intercept as shown in Fig. 5.



(a) Slop



(b) y-Intercept

Fig.5. Correction scenarios of Q-V curve

The difference between the values of P and P_O is passed through the proportional integral controller. Then the controller regulates the values of K_Q and y-intercept as illustrated in Eq. (6). Rate limiter used to acquire the required values of ΔK_Q and ΔV_o.

$$V = Vo - K_Q . Q + \left(\frac{I_C}{s}\right) . (P - P_O) \qquad (6)$$

Where I_C is Integral gain.

If the value of Q is greater than Q_o in one DG unit then the value of the term $(D_P P+D_Q Q)$ will decrease. According to the Eq. (5), a decrement will occur in term $(D_P P+D_Q Q - \omega_o)$ decrease the frequency which ultimately increase the P. This change in P from P_o is used as the correction procedure for the slop and y- as shown in Fig. 2. The difference between the values of P_o and P is passed through the PI controller. Then the controller regulates the values of K_Q and y-intercept as illustrated in Eq. (6). Rate limiter used to acquire the required values of ΔK_Q and ΔV_o.

When the compensation procedure of the reactive power is completed and Q is equal to Q_O then the active power flow will move back towards its real value with the controlling of Eq. (5). Compensation of Q will occur at the level of the primary control. This technique will not affect the procedure of the secondary control.

After successful completion of reactive power compensation scheme reference voltage will be generated as shown in Fig.6. Compensation scheme will be expired at this stage and the system will go back to the conventional droop method.

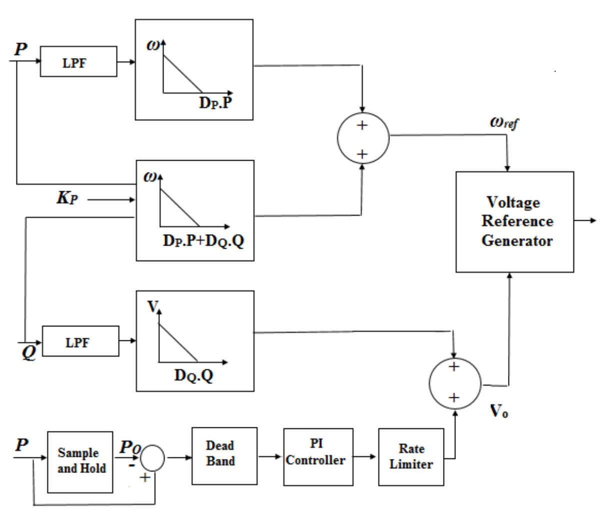


Fig.6. Synchronized Reactive Power Compensation Scheme

4. RESULTS AND DISCUSSIONS

The test system is setup in MATLAB/Simulink to access the proficiency of the proposed methodology.

There are four case studies to analyze the accuracy of the proposed technique:

Case 1: Reactive power sharing accuracy by utilizing the proposed methodology.

Case 2: Enhancement in reliability as compared to the communication-based methods.

Case 3: System response in case of load variations.

Case 4: Feeder Faults influence on the performance of the proposed methodology.

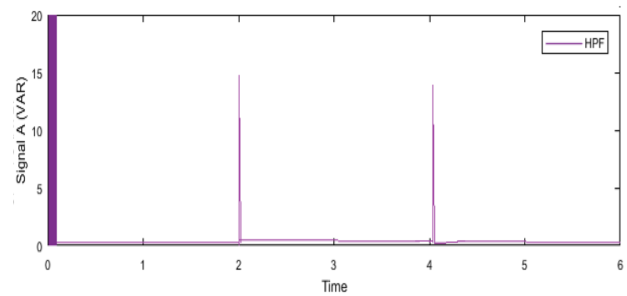
Case 1: Reactive power sharing accuracy by utilizing the proposed methodology

In this case, microgrid is shifted to islanded mode with two DGs (DG_1 & DG_2). At this stage, one common load (1176W, 476VAR) and one local load (2000W, 520VAR) is connected to the system. One local load (1176W, 476VAR) is also added to the DG1 once the grid is disconnected from the system. The load is doubled at t=2s. As load is suddenly greater than the capacity of 2DGs, the 3rd DG will start sharing its power at t=4s. Table 2 shows the switching strategy of the proposed methodology.

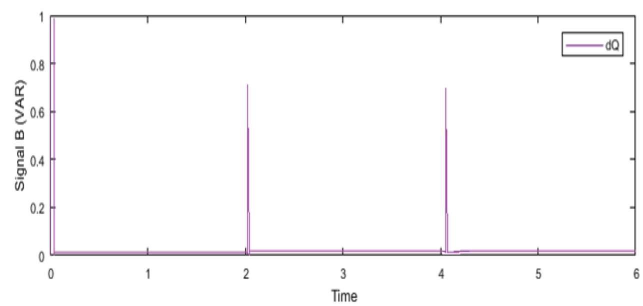
Table 2. Switching Sequences of the proposed methodology

Periods	Switches					
	S_1	S_2	S_3	S_4	S_5	S_6
$0 \le t < 2$	0	1	0	1	0	1
$2 \le t < 4$	0	1	1	1	0	1
$4 \le t < 6$	1	1	1	1	0	1

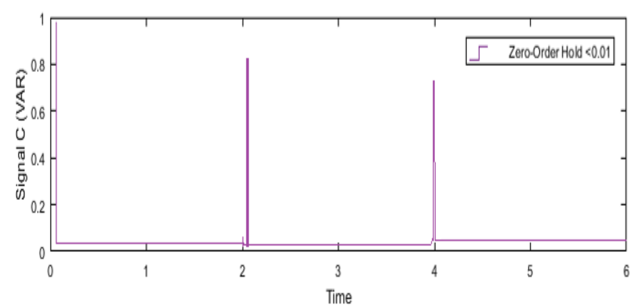
Fig. 7 (a), (b), (c), (d), (e) and (f) describe the point by point formation of the local starting flag. Signal 'A' in Fig. 7 (a) describes the overshoot time of the network when DG operating point is changing. Signal 'B' in Fig. 7(b) shows the response of the comparator which comes from the subtraction of |dQ| and the pre-defined value of Q. Small sampling period (0.004s) is required to remove the fluctuations of load changes. It forms the signal 'C' as shown in Fig. 7(c). Large sampling period (0.047s) is required for the removal of fluctuations of the MG mode transfer and the DG switching. It forms the signal 'D' as shown in Fig. 7(d). Combination of signal 'C' and 'D' forms the signal 'E' as shown in Fig. 7(e). This signal 'E' is named as '$S_{Control}$'. To make this signal uniform edge detector block is utilized. Signal 'F' in Fig. 7(f) demonstrates the applicability of the proposed methodology for different types of events. Fig. 8(a) & 8(b) shows that the active and reactive powers are properly shared among 3 DG units Fig. 8(c) shows that the V_{PCC} also remains within the allowable range of 114-116V without any disturbance.



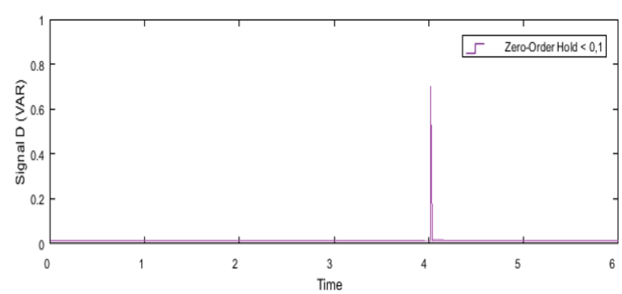
(a) Signal A



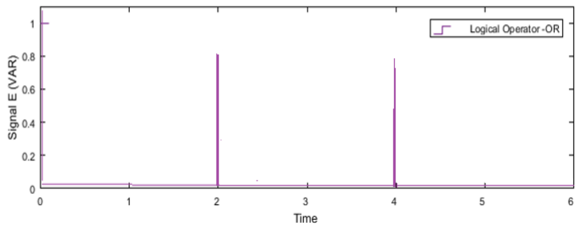
(b) Signal B



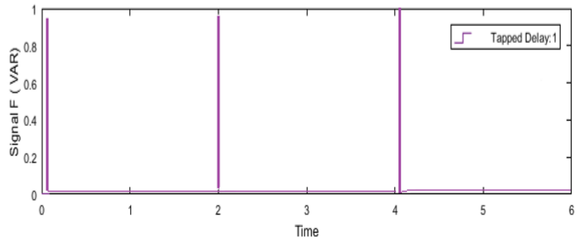
(c) Signal C



(d) Signal D

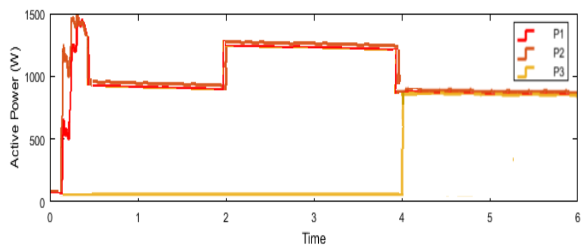


(e) Signal E

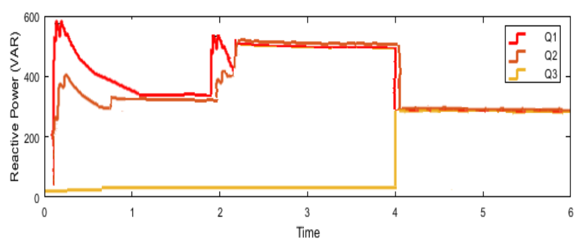


(f) Signal F

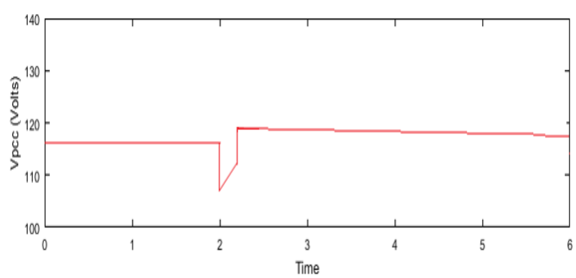
Fig.7. Control Signals related to the different steps of start recognition Scheme



(a) Active Power sharing



(b) Reactive Power Sharing

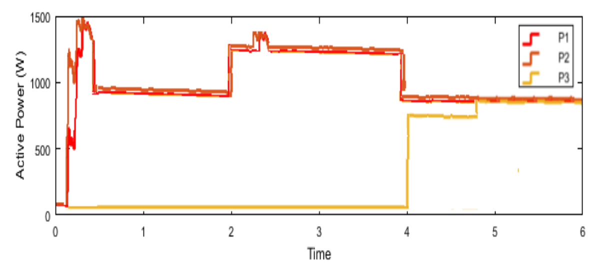


(c) Common Bus Voltage

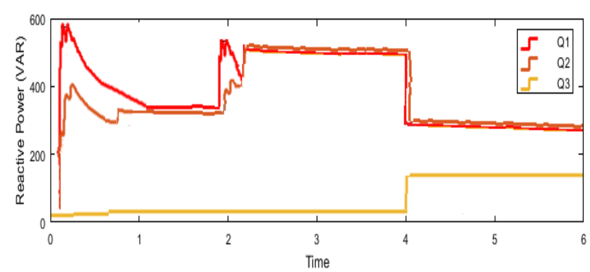
Fig. 8. Power & Voltages using Proposed topology

Case 2: Enhancement in reliability as compared to the communication-based methods

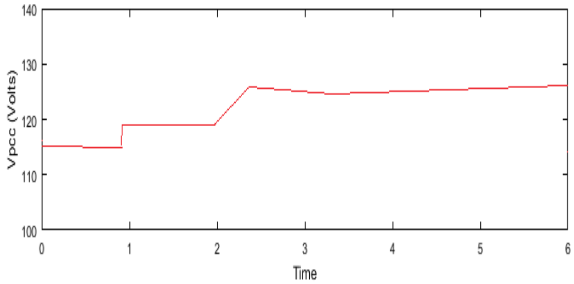
This section demonstrates the comparison of communication based system and the proposed local start recognition scheme. In communication based systems real power is accurately sharing across 3 DGs while the reactive power sharing is not properly acquired. At t=2s, the load becomes double. Hence DG3 moved to the on position at 4s. In the period of 2-4s, reactive power sharing is appropriate among 2 DGs. Operating point variations during the (4-6s) create errors in the accuracy of reactive power sharing. Hence, for the DG_3, the correction scheme is not properly started. This issue creates the fluctuations across the output of the 3 DGs as demonstrated in Fig. 9 (a) & (b). By utilizing the proposed methodology, the nominal voltage remained in the allowable range of 114-116V. However, in communication-based method nominal voltage reached to the value of 126 V which is not acceptable as shown in fig 9 (c). If there is no voltage limiter then absence of communication signal may lead microgrid into instability. The comparison of Fig. 8 (a) and 9 (a) respectively shows that the proposed method accurately restores the P_o in just 0.5s while communication-based methods can disturb the actual value of the real power due to the delays in communication [11]. Hence, it is proved that the advanced local based triggering mechanism increase the reliability of the system.



(a) Active power Sharing



(b) Reactive Power Sharing



(c) Common Bus Voltage

Fig. 9. Power & Voltage sharing in communiction based systems

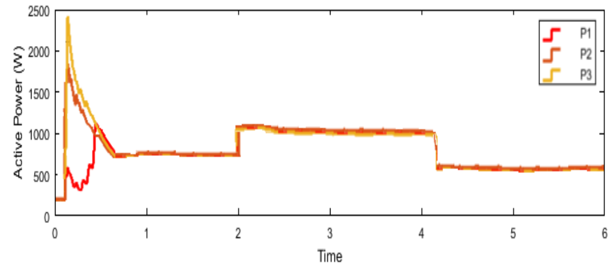
Case 3: System response in case of load variations

Changes in local loads is become a vital challenge when the equal sharing of the load demands across DGs is required. Also, it can be said that the variations in local loads make the different types of feeders asymmetric and generate a sensitive circumstance to achieve the requisite objectives, as the proper voltage or the appropriate reactive power sharing. The third case study analysis is planned by exchanging the switching strategies of the switches S4 and S5 as shown in table 3.

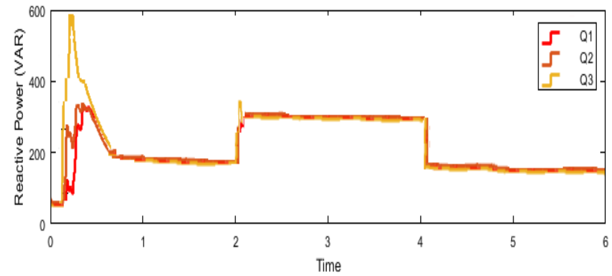
Table 3. Switching Sequences of the System response in case of load variations

Period	**Switches**					
	S_1	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**
$0 \leq t < 2$	1	1	0	0	1	1
$2 \leq t < 4$	1	1	0	1	1	1
$4 \leq t < 6$	1	1	0	1	0	1

Fig. 10 (a) & (b), shows the considerable change in the local loads during the timing of 2s and 4s respectively. At start of this case one local and one common load is connected to the network. Suddenly, at t=2s load at DG_1 becomes double. There are fluctuations in the reactive power sharing due to the variation in DGs operating point. In this result, the correction scheme of reactive power sharing is properly started at t=3s. Hence reactive and active power are adequately shared among 3 DGs as shown in Fig 10 (a) & (b). At t=4s, local load at DG_1 is decreased. After that the correction scheme is properly started. Hence reactive power is appropriately shared across 3 DGs as shown in Fig 10 (a) & (b).



(a) Active Power Sharing



(b) Reactive Power Sharing

Fig.10. Sharing of Powers in case of load variations

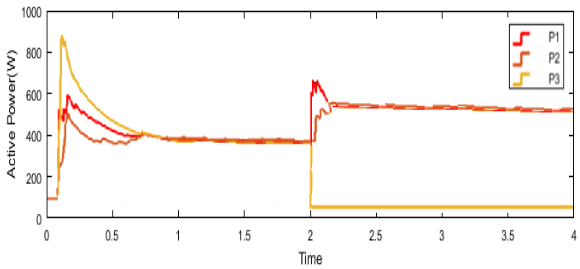
Case 4: Feeder Faults influence on the performance of the proposed methodology

This case analyzes the feeder double phase and threes faults impact on the proposed topology. These faults occurred at t=3s in the case of DG_3.Table 4 describes the switching sequences.

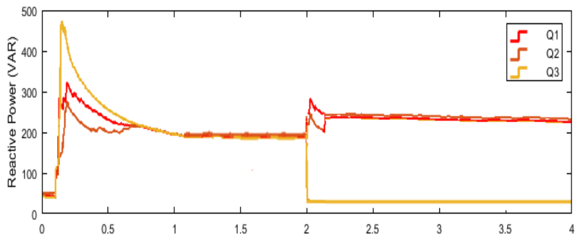
Table 4. Switching Sequences of the feeder faults influence on the proposed topology

Period	**Switches**					
	S_1	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**
$0 \leq t < 2$	0	1	0	0	1	1
$2 \leq t < 4$	1	1	1	0	1	1

Inverter based MG has small fault currents (= 1-2 pu) as compared to the traditional generator-based method (=5-10 pu) [14]. That's why real and reactive power sharing has not been adequately done across 3 DGs [15]. As Fig.11 (a) & (b) show that the double phase ground faults occurred at DG_3 then it moves towards the off position [16]. After t=2s $DG_1$and DG_2 have accurately shared the reactive and real powers across DGs. Fig.12 (a) & (b) show that the three phase faults occurred at DG_3 then it moves towards the off position. After that the powers are accurately shared across the two DGs.

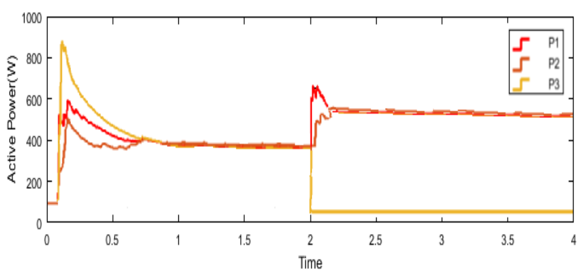


(a) Active Power Sharing

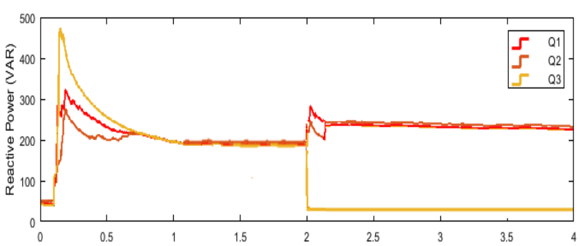


(b) Reactive Power Sharing

Fig. 11. Power sharing in case of double phase to ground faults.



(a) Active Power Sharing



(b) Reactive Power Sharing

Fig. 12. Sharing of Power in case of three phase faults

6. CONCLUSION

In this work, a local based triggered reactive power correction scheme is dictated. The variations in reactive power have been observed against any powerful changes in DGs operating points which can be due to load diversity, mode exchange or the DG switching of a MG. Operating point variation is used as the starting flag for the reactive power compensation scheme. It injects the transient reactive power in the P-ω droop control. Transient Q has generated disturbance in the active power. Disturbed active power will be helpful for the calculation of reactive power sharing error. To resolve the error, proportional integral controller will modify the values of the slop and y-intercept of conventional voltage droop curve. Simulation results shows that the proposed topology acquired the appropriate real power and reactive power sharing across DGs as expected. Moreover, this technique will decrease the cost and make the network more stable and reliable as compared to the communication-based methods.

REFERENCES

[1] F. Katiraei, R. Iravani, N. Hatziargyriou, and A. Dimeas, "Microgrid Management," *IEEE power energy Mag.*, vol. 6, no. june, pp. 54–65, 2008.

[2] Han *et al.*, "Aalborg Universitet Review of Power Sharing Control Strategies for Islanding Operation of AC Microgrids," *I E E E Trans. Smart Grid*, vol. 7, no. 1, pp. 200–215, 2016.

[3] D. E. Olivares *et al.*, "Trends in microgrid control," *IEEE Trans. Smart Grid*, vol. 5, no. 4, pp. 1905–1919, 2014.

[4] C. K. Sao and P. W. Lehn, "Autonomous Load Sharing of Voltage Source Converters," *IEEE Trans. Power Deliv.*, vol. 20, no. 2, pp. 1009–1016, 2005.

[5] Y. W. Li and C. N. Kao, "An accurate power control strategy for power-electronics-interfaced distributed generation units operating in a low-voltage multibus microgrid," *IEEE Trans. Power Electron.*, vol. 24, no. 12, pp. 2977–2988, 2009.

[6] E. Rokrok and M. E. H. Golshan, "Adaptive voltage droop scheme for voltage source converters in an islanded multibus microgrid," *IET Gener. Transm. Distrib.*, vol. 4, no. 5, p. 562, 2010.

[7] W. Yao, M. Chen, J. Matas, J. M. Guerrero, and Z. M. Qian, "Design and analysis of the droop control method for parallel inverters considering the impact of the complex impedance on the power sharing," *IEEE*

Trans. Ind. Electron., vol. 58, no. 2, pp. 576–588, 2011.

[8] J. M. Guerrero, J. Matas, L. G. de Vicuna, M. Castilla, and J. Miret, "Decentralized control for parallel operation of distributed generation inverters using resistive output impedance," *IEEE Trans. Ind. Electron.*, vol. 54, no. 2, pp. 994–1004, 2007.

[9] Q. C. Zhong, "Robust droop controller for accurate proportional load sharing among inverters operated in parallel," *IEEE Trans. Ind. Electron.*, vol. 60, no. 4, pp. 1281–1290, 2013.

[10] H. Han, Y. Liu, Y. Sun, M. Su, and J. M. Guerrero, "An improved droop control strategy for reactive power sharing in islanded microgrid," *IEEE Trans. Power Electron.*, vol. 30, no. 6, pp. 3133–3141, 2015.

[11] J. He and Y. W. Li, "An enhanced microgrid load demand sharing strategy," *IEEE Trans. Power Electron.*, vol. 27, no. 9, pp. 3984–3995, 2012.

[12] A. Gandhi and D. R. Kishore, "Reactive Power Sharing Droop Control Strategy for DG Units in an Islanded Microgrid," no. July, 2016.

[13] J. M. Guerrero, J. C. Vasquez, J. Matas, L. G. De Vicuña, and M. Castilla, "Hierarchical control of droop-controlled AC and DC microgrids - A general approach toward standardization," *IEEE Trans. Ind. Electron.*, vol. 58, no. 1, pp. 158–172, 2011.

[14] H. R. Baghaee, M. Mirsalim, G. B. Gharehpetan, and H. A. Talebi, "Nonlinear Load Sharing and Voltage Compensation of Microgrids Based on Harmonic Power-Flow Calculations Using Radial Basis Function Neural Networks," *IEEE Syst. J.*, pp. 1–11, 2017.

[15] H. Zhang, S. Kim, Q. Sun, and J. Zhou, "for Accurate Reactive Power Sharing Based on Consensus Control in Microgrids," *IEE Trans. Smart Grid*, pp. 1–13, 2016.

[16] K. O. Oureilidis and C. S. Demoulias, "A Fault Clearing Method in Converter-Dominated Microgrids with Conventional Protection Means," *IEEE Trans. Power Electron.*, vol. 31, no. 6, pp. 4628–4640, 2016.