

REDUCTION OF ISLANDING EFFECTS BY IMPLEMENTATION OF NEW CONTROL STRATEGY USING ANN BASED PI CONTROLLER

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Abstract

Distributed generation plays a significant role in power generation, but the standalone system has some limitations like excess power generation and sudden increment in load. Grid interconnected DG system mitigates all this type of problems but some different questions arise in this interconnection. How to synchronize the DG system with the grid? If any change in voltage or frequency they lead to disconnect the grid from DG system. But due to sudden loose of grid supply, the phase angle is changed in filter terminal voltage and leads same change in load voltage because when the grid is connected the load receives power from both DG and grid. In grid-connected system current controller is generally used, to maintain the constant current in load side, so in islanding conditions, the voltage profile will get

damage and power factor is also dropped. This paper proposes a strategy of two controllers for both grid-connected and intentional islanding modes. PI controller based constant current regulator for grid-connected mode, while ANN based VC controller for intentional islanding mode. These two controllers are operated according to changes occurred at Point of Common Coupling (PCC).

Key Words: ANN based VC controller, current controller, distributed generation, intentional islanding, grid-connected DG system, the point of common coupling.

1 Introduction

The DG is very useful in the case of “blackout”, due to different reasons like voltage, frequency dropouts. The DG is defined as the generation center is located at the load centers for power supplies. Generally, buildings are the one example the top of the buildings PV panels are placed the generated power is utilized by the consumers on the building. The excess power is connected to the grid. The anti-islanding circuits are provided for the continuous operation. In the proposed case, intentional islanding is done for the constant voltage maintenances in the load center. The intentional islanding test is very useful for DG system because the grid line is suddenly cut-off from the tie-line (P.C.C.). The most effective advantage of the PV connected grid system increases the effective utilization of power because the storage system is not required when there are no storage losses.

A standalone system is not suitable for dynamic load changer so it needs without any fluctuations in output response so primary option is connecting a battery system to solar system but it is very costlier, so if the right conditions are possible the distributed generation system is connected to grid in the case the excess power is given to grid & at high load conditions or suddenly load increased conditions grid supplies the power to load centers. By supplying excesses power to the grid there is two advantageous

- i) To avoid power wastage
- ii) To generate the income by selling the excesses power to the grid depending on the agreement between both DC system and grid.

2 LITERATURE REVIEW

The Robust damping controllers are used to control the faulty current and disturbance from the external sources. The dg system with polytypic problems is reduced by using LCL filters and by the use of LCL filters the transient response is very fast and small peak overshoots [1]. The grid frequency fluctuations are a major problem when connected to the DG system & it should be eliminated or greatly reduced to protect the synchronization of grid and dg system. The feedback controllers are very much required for these problems. The robust grid current feedback active damping controller provides the constant current to the load center.

The synchronous reference frame quasi PI controller is required in some areas to get the good stability margin along with resonant peak under the impedance variations of the grid system. The RGCDFD & SRFQPI are used to compensate PQ variations under heavy loads & light load conditions for sudden step response [2].

In DG connected systems the reactive power variations are very common but they may lead to change the frequency values also. The quasi-proportional resonant controller provides the improvement in the reactive power & reactive current responses by using the reactive current detective algorithms & it can perform better when compared to regular phase delay controller. The dc link voltages may also improve by using this type of controllers. The stability margin improvements are also analyzed by the bode plot for clear observations [3].

$$i_d = \sqrt{\frac{2}{3}} \left\{ i_a * \cos \theta - i_b * \cos\left(\theta + \frac{2\pi}{3}\right) - i_c * \cos\left(\theta - \frac{2\pi}{3}\right) \right\} \quad (1)$$

$$i_q = \sqrt{\frac{2}{3}} \left\{ i_a * \sin \theta - i_b * \sin\left(\theta + \frac{2\pi}{3}\right) - i_c * \sin\left(\theta - \frac{2\pi}{3}\right) \right\} \quad (2)$$

$$i_0 = \frac{1}{\sqrt{3}} \{ i_a + i_b + i_c \} \quad (3)$$

$$v_d = \sqrt{\frac{2}{3}} \left\{ v_a * \cos \theta - v_b * \cos\left(\theta + \frac{2\pi}{3}\right) - v_c * \cos\left(\theta - \frac{2\pi}{3}\right) \right\} \quad (4)$$

$$v_q = \sqrt{\frac{2}{3}} \left\{ v_a * \sin \theta - v_b * \sin\left(\theta + \frac{2\pi}{3}\right) - v_c * \sin\left(\theta - \frac{2\pi}{3}\right) \right\} \quad (5)$$

$$v_0 = \frac{1}{\sqrt{3}} \{v_a + v_b + v_c\} \quad (6)$$

In matrix form, it can be represented as

$$\begin{bmatrix} i_o \\ i_d \\ i_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \\ \cos \theta & \cos\left(\theta + \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{2\pi}{3}\right) \\ \sin \theta & \sin\left(\theta + \frac{2\pi}{3}\right) & \sin\left(\theta - \frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (7)$$

$$I_{dqo} = P * I_{abc} \quad (8)$$

Similarly

In matrix form, it can be represented as

$$\begin{bmatrix} v_o \\ v_d \\ v_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \\ \cos \theta & \cos\left(\theta + \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{2\pi}{3}\right) \\ \sin \theta & \sin\left(\theta + \frac{2\pi}{3}\right) & \sin\left(\theta - \frac{2\pi}{3}\right) \end{bmatrix} \times \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (9)$$

$$V_{dqo} = P * V_{abc} \quad (10)$$

Load shedding is one of the best adaptive methods for balancing of both voltage and frequency variations. It will give the optimal way of the solution in emergency conditions by avoiding the interruption of power supply to a high number of consumers. Most commonly it also named "Defense Plan" [4]. In wind energy based DG systems facing two types of problems: i) The output power from the wind systems are not constant in a day/month. So the maximum power point tracker needs to avoid this type of problems. ii) Load side voltage and frequency problems due to sudden load shedding and it can be overcome by providing constant voltage controller along with frequency controller [5]. The renewable energy sources are not producing consistent energy over a day and the grid-connected renewable energy systems are creating the problems by varying the voltage levels, it may lead to "blackouts". To avoid this type of problems due to inconsistent energy supplies the islanding technique is introduced to protect the grid [6], [7].

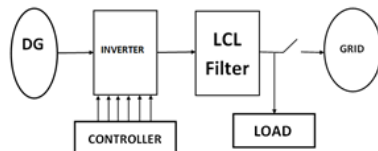


Figure 1: Grid inter-connected Distributed Power Generation with LCL filter.

3 PROPOSED STRATEGY

The inverter is placed between the PV systems to AC side. The inverter should monitor the voltage response of the grid continuously because of the synchronization process. The inverter always produces slightly higher than the grid voltage for the smooth power flow outward from the solar energy.

Grid-Connected Mode:

In general, all the microgrids/DG systems are operated under constant current control mode. In this mode, the load current is constant w.r.t. reference value.

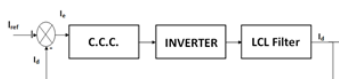


Figure 2: Block Diagram of Constant Current Controller.

The constant current controller is preferred based on the fast response and it directly controllers the load current which helps in the power supply reliability. The controller operation is explained the next section.

Islanding Mode/Grid Disconnected Mode:

Islanding situation occurs due to the deviation of voltage/ frequency levels violation and it directly affects the grid synchronization. The intentional islanding is proposed in this paper by providing the comparison of grid voltage and DG system voltage levels as well as the frequency of the grid and DG system. If any deviation occurs then it sends the signal, to disconnect the DG system from the healthy grid. In this condition, the voltage and current are not maintaining constantly because the phase angle is changed due to sudden disconnection of one source and the deviated phase

angle causes the low power factor. To avoid all these problems, the paper proposes ANNVCR for grid islanding conditions. By this controller the new phase angle is established, then the voltage and current levels are maintained constantly.

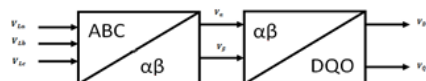


Figure 3: Conversion of load Voltage by using Parks Transformation

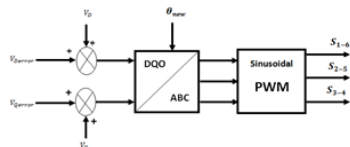


Figure 4: Inverter switching pulses calculation by using error values.

Constant Current Controller (CCC):

Figure 2 shows the current controller which helps to maintain constant current as an output. The frequency will be determined by the device phase locked loop (PLL) and it also produces the reference angle of the point of common coupling. The reference angle is an important aspect for grid-connected DG systems synchronization.

In current control mode, the output of the filter is transferred to the synchronous frame by using parks transformation equation (1).

Where $\theta = \omega t$ and ω is the frequency of the electric system.

The error detector is used to find an error in DC quantity by comparing the i_{dref} , i_d and i_{qref} , i_q and it is connected to PI controller (current controller), then the current controller produces values of v_d , v_q . The error detector is used one more time to produce a required terminal voltage by comparing error signals of v_{derr} , v_{qerr} and output value of v_d , v_q . The inverse parks transformation is used to convert DC quantities of voltage into three phases. The phase angle is reestablished by generating new value by PLL.

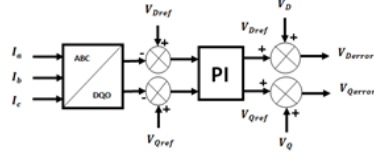


Figure 5: Block diagram representation of error calculations.

ANN Based Voltage Current Regulator (ANNVCR):

ANNVCR is mainly used in grid islanding condition due to uncontrolled voltage magnitude and phase angle. In general, the grid-connected condition the voltage levels are monitored by PCC and the controller is provided only for constant current levels but in the islanding condition already the voltage/frequency levels deviate from the fixed values. Now the controller needs to maintain both the current and voltage as well as phase angle establishment. But it also has one limitation, i.e., the ANNVCR response is slow when compared to the constant current controller because if write the transfer function of the two controllers the ANNVCR has one additional pole. The additional pole gives the more stable conditions but response time is slow when compared to CCC.

In this controller, the voltage is compensated through the current regulator. The load voltage is converted into dqo form by using parks transformation, to get the V_D, V_Q . The error will be calculated by using an error detector with a comparison of V_{Dref}, V_{Qref} . The error is generated & it is fed to voltage regulation to generate current reference signals I_{Dref}, I_{Qref} . The I_{Dref}, I_{Qref} are fed to error detector by combining I_D, I_Q . Now the process will be same as a current controller because the error signals current will feed to current regulator. Finally, the high switching pulses are generated by using SPWM. The Transfer Function of the ANNVCR can be expressed as equation (23).

$$i_a = \{-i_d * \cos \theta + i_q * \sin \theta + \frac{1}{2}i_0\} \quad (11)$$

$$i_b = \{-i_d * \cos(\theta - \frac{2\pi}{3}) + i_q * \sin(\theta - \frac{2\pi}{3}) + \frac{1}{2}i_0\} \quad (12)$$

$$i_c = \{-i_d * \cos(\theta + \frac{2\pi}{3}) + i_q * \sin(\theta + \frac{2\pi}{3}) + \frac{1}{2}i_0\} \quad (13)$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} -\cos \theta & \sin \theta & \frac{1}{2} \\ -\cos(\theta - \frac{2\pi}{3}) & \sin(\theta - \frac{2\pi}{3}) & \frac{1}{2} \\ -\cos(\theta + \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} \quad (14)$$

$$v_a = \{-v_d * \cos \theta + v_q * \sin \theta + \frac{1}{2}v_0\} \quad (15)$$

$$v_b = \{-v_d * \cos(\theta - \frac{2\pi}{3}) + v_q * \sin(\theta - \frac{2\pi}{3}) + \frac{1}{2}v_0\} \quad (16)$$

$$v_c = \{-v_d * \cos(\theta + \frac{2\pi}{3}) + v_q * \sin(\theta + \frac{2\pi}{3}) + \frac{1}{2}v_0\} \quad (17)$$

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} -\cos \theta & \sin \theta & \frac{1}{2} \\ -\cos(\theta - \frac{2\pi}{3}) & \sin(\theta - \frac{2\pi}{3}) & \frac{1}{2} \\ -\cos(\theta + \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) & \frac{1}{2} \end{bmatrix} \begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} \quad (18)$$

$$v_a = \{\frac{2}{3}v_{ab} + \frac{1}{3}v_{bc}\} \quad (19)$$

$$v_\beta = (\frac{1}{\sqrt{3}})v_{abc} \quad (20)$$

$$V_D = -V_\alpha * \cos \theta + V_\beta * \sin \theta \quad (21)$$

$$V_Q = V_\alpha * \cos \theta + V_\beta * \sin \theta \quad (22)$$

$$T(s) = \frac{s^4 + 8.79 * 10^3 s^3 + 6.56 * 10^7 s^2 + 8.06 * 10^9 s + 6.45 * 10^7}{s^5 + 1.42 * 10^4 s^4 + 1.46 * 10^8 s^3 + 6.44 * 10^{11} s^2 + 3.49 * 10^{13} s + 2.79 * 10^{11}} \quad (23)$$

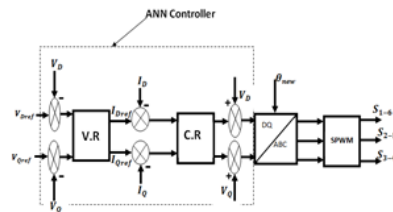


Figure 6: Block Diagram of ANN based Constant Voltage Current Regulator.

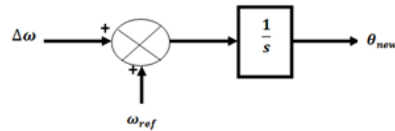


Figure 7: Block Diagram for new phase angle calculation.

%pi tried

```
P=[Output Data];
T=[Input Data];
net=newff(minmax(P),[1 21 1],{'tansig','tansig','purelin'},'trainlm');
net.trainParam.show=50;
net.trainParam.lr=0.05;
net.trainParam.mc = 0.95;
net.trainParam.lr_inc = 1.9;
net.trainParam.lr_dec = 0.15;
net.trainParam.epochs=500;
[net,tr]=train(net,P,T);
a=sim(net,P);
gensim(net,-1);
```

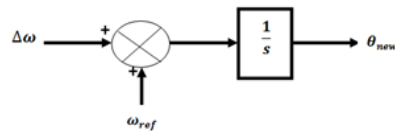


Figure 7: Block Diagram for new phase angle calculation.

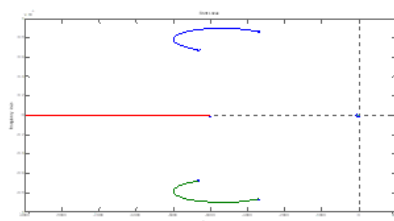


Figure 8: Stability analysis for ANN based Constant Voltage Current Regulator.

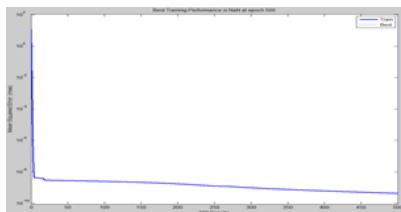


Figure 9: ANNVCR Mean Square Error response.

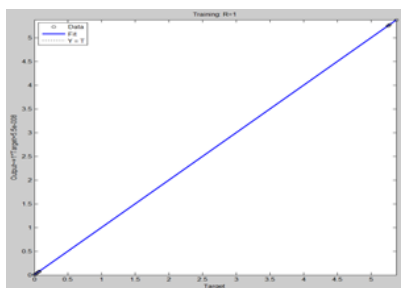


Figure 10: Regression of trained ANN.

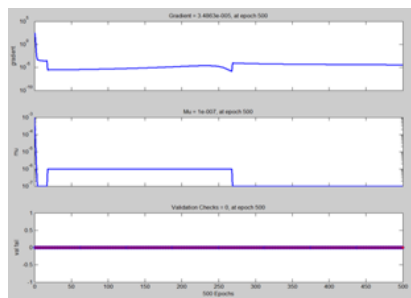


Figure 11: Response of gradient, mu, val fail w.r.t. Epochs.

4 RESULTS & DISCUSSION

The figure shows the voltage response of the distributed power system and it is collected from the end terminals of the LCL filter, which is directly connected to Grid via PCC. The total response of the system is shown in that figure. From the 0 to 0.2 sec the DG and Grid systems are connected but at 0.2sec the grid is intentionally disconnected from the DG due to change in voltage of the DG system. In general, the constant current controller is used for the

Grid connected DG systems because the grid is connected to any DG system when the voltage and frequencies are same. But in this paper the grid is islanded from DG system by the change in frequency at the instant 0.2 sec, therefore the voltage is not controlled in the DG system and phase sequence is also changed and it can be observed clearly in the extended view of the DG system Voltage response because in that controller there is no control over voltage, it regulates only the current value in the load center properly.

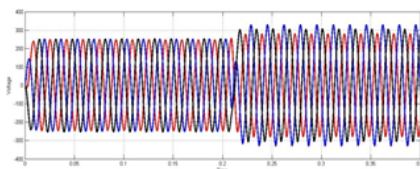


Figure 12: Three Phase Voltage of Distributed Generation system output.

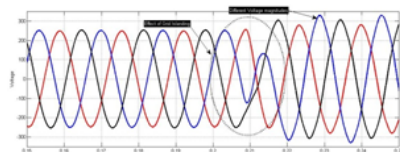


Figure 13: Expanded view of DG output voltage under islanding condition.

The above figure shows the extended view of the DG output response observe the dotted ellipse portion the voltages are going out of phase in that instant because of grid islanding & this phenomenon leads to poor power factor. The voltage magnitude is also changed in three phases and it is also represented by arrow line. Most of the time all these issues lead to voltage collapse because of unequal phase angle differences and low power factor.

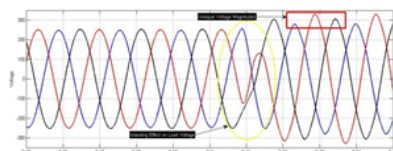


Figure 14: Expanded view of load voltage variations under grid islanding conditions without voltage regulation.

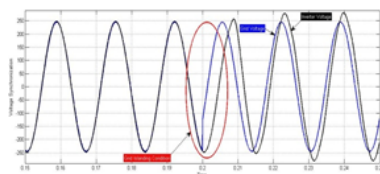


Figure 15: Expanded view of synchronization of DG & Grid voltage responses without voltage regulation.

From the synchronization graph we can observe from 0 to 0.2 sec the grid voltage and DG system output voltages are in phase when the disturbances occurred in the DG system then the grid is disconnected from DG system and the islanding is occurred in DG side, in that instant onwards the phase angle of the inverter voltage is changed along with its magnitudes. Even after some time duration also the disturbance is not cleared by this constant current controller.

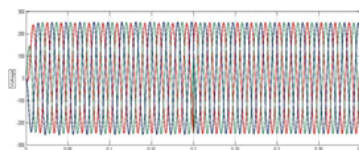


Figure 16: DG system output voltage response under both Grid-connected and islanding cases with both ANNVCR.

The above figure shows the output voltage response of the DG system with ANN controller, the effect of islanding condition is limited to very few milliseconds and the DG system output voltage magnitude is maintained constant even though the grid is disconnected from the DG system.

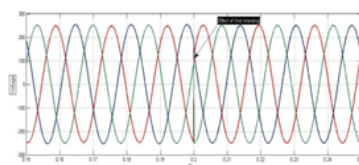


Figure 17: Expanded view of DG output voltage response under islanding condition ANNVCR.

The above figure shows the expanded view of the DG system output voltage from 0.15 to 0.25 sec. At 0.2 instant the voltage response

suddenly collapsed but it is limited that particular time only i.e. 0.2 by providing the islanding detector it senses the islanding situation in the system and immediately changes the controller from the constant current controller to ANN controller. Even after islanding state, the phase sequence is not changed in the output voltage of the DG system and the same time the voltage magnitude is also constant.

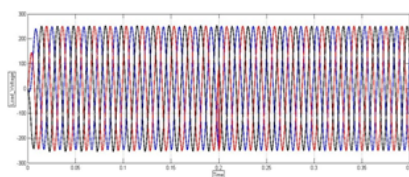


Figure 18: Voltage response of load center with ANNVCR.

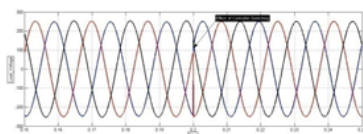


Figure 19: Expanded view of voltage response in load side at 0.2 islanding instant ANNVCR.

The above figures show that voltage response of the load center and expanded the view of voltage response at islanding situations. In general, load receives the current from grid side and DG side but in the islanding situation there is no supply from the grid side and completely based on DG system only, the voltage is also disturbed in that condition but with the use of ANN controller the voltage variations are mitigated.

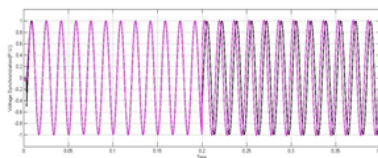


Figure 20: Synchronization of Grid voltage and DG system output voltage ANNVCR.

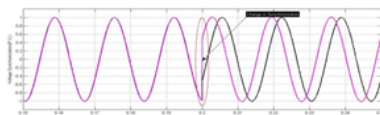


Figure 21: Expanded view of Synchronization under islanding condition ANNVCR.

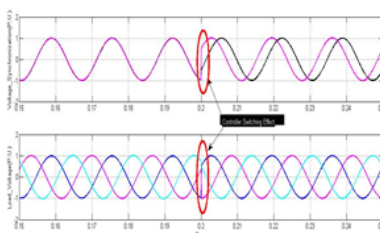


Figure 22: Expanded view of load voltage and voltage synchronization ANNVCR in per unit representation.

The above figure shows the expanded view of the load voltage and synchronization of the DG system output voltage and grid voltage. The islanding condition is marked with the red mark ellipse due effect of switching controller action from constant current controller to ANN controller the sequence and magnitude are reestablished. We can compare the two control schemes by synchronization graph with the help of ANN voltage phase angle is not changed even after grid islanding condition but in the first case i.e. in constant current controller case the phase angle difference is not equal and magnitude is different in three phases of the DG system flowed by load center. The PV system acts as a distributed power generation and the PV system is connected to an inverter, to change the dc power supply into AC world. The resonant filter (LCL) is used for a perfect sine wave. The filter terminals are connected to three phase grid via PCC. The load is located after the filter terminals. Under normal operating conditions (i.e., grid-connected systems) the current controller is used to maintain the constant current in the load center. In normal operating condition, the synchronization is already established between DG systems to grid. In this condition, the following should be maintained:

- Voltage levels should be same.
- Frequency should be same.
- Phase sequence is also same.

By all these conditions, at load centers constant. Voltage level should be maintained because of synchronization. Additionally, the current controller provides a constant current. Therefore in the load centers constant current, voltages are available with same phase sequence. If the grid is disconnected due to any technical problem (generally because of variations in frequency, voltage levels), the phase sequence is changed and voltage levels are also changed & the controller provides only constant current in load center but due to phase sequence variations the load centers don't work properly and the power factor is decreased due to voltage phase angle variations. In this standalone condition, we proposed an ANN controller for both constant voltage & current.

$$\begin{aligned}
 k &= V_{ina}V_{Ga} + V_{inb}V_{Gb} + V_{inc}V_{Gc} \\
 k &= \frac{3}{2} \cos \theta \\
 g &= V_{ina}V_{Ga} + V_{inb}V_{Gb} + V_{inc}V_{Gc} \\
 g &= \frac{3}{4} - \cos \theta + \sqrt{3} \sin \theta \\
 \cos \theta &= \frac{2}{3}k \\
 -\cos \theta &= \frac{4}{3}g - \sqrt{3} \sin \theta \\
 \cos \theta &= \sqrt{3} \sin \theta - \frac{4}{3}g
 \end{aligned}$$

From above two equations,

$$\begin{aligned}
 \frac{2}{3}k &= \sqrt{3} \sin \theta - \frac{4}{3}g \\
 \sqrt{3} \sin \theta &= \frac{4}{3}g + \frac{2}{3}k \\
 \sin \theta &= \frac{1}{3\sqrt{3}}\{4g + 2k\}
 \end{aligned}$$

The ANN controller is used to maintain the constant voltage levels in the inverter output terminals as well as load centers also. In this ANN controller, the input response is an error in voltage V_{Dref} , V_D and V_{Qref} , V_Q are compared to producing the error value and it is sent to ANN controller. It contains two regulators first one is voltage regulator and the second one is the current regulator. The voltage regulator receives the error quantity & integrates the error value and changed to current quantities respectively based on historical databases by trained ANN controller.

The output of the ANN-based voltage regulator is I_{Dref} , I_{Qref} . The current value collected from load side is converted into D_{Qo} form compared with the output response of the voltage regulator I_{Dref} , I_{Qref} . Now the error detector generates the error value in

terms of current quantity. The error values are collected by the current regulator and it acts as an integrator and generates the required voltage level in terms of magnitude and phase angle. The output compensated voltage is added to V_D, V_Q respectively. But all these quantities present in the D_Q form and it is converted to ABC form by inverse parks transformation. The angle new will generates by using fig7. The θ new will help to re-establishes the voltage levels in three phase system with phase angle.

The SPWM technique is used to generate the pulses required for the three-phase inverter the output of ANN controlled and compared with carrier signals then it generates the required pulses.

5 CONCLUSION

Through this Paper, two control strategies are implemented along with islanding detection algorithm, for Grid-Connected and islanding mode operations in the distributed power system. From the results which are shown in the previous section that clears, proposed control strategy is capable of maintaining constant voltage and current levels at load centers in grid-connected and islanding conditions. By ANNVCR, voltage fluctuations are mitigated and voltage, current levels are maintained in acceptable levels when grid-connected and islanding DG system from remaining utility system.

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