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Power Quality Profile Enhancement of Utility connected Microgrid System using ANFIS-UPQC

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Abstract

This paper investigates compensation of power quality issues of utility connected microgrid system using unified power quality conditioner (UPQC) device. A very important task on integration of utility and microgrid is the power flow management and compensation of power quality (PQ) distortions. Among all power quality distortions, the voltage drop and harmonic distortions are serious PQ distortion occur in the utility and customer side respectively. The UPQC is a promising device to compensate both utility and customer side PQ distortions. The compensation capability of the traditional UPQC device is limited by the DC link voltage regulation using conventional PI controller. In proposed control technique, the compensation capability of the UPQC device is enhanced by an adaptive neuro fuzzy inference system (ANFIS) based reference DC link voltage estimation and DC link voltage regulation. The ANFIS is trained off-line and implemented in the online simulation. Finally, the proposed ANFIS based UPQC is investigated for compensating PQ distortions originated in utility connected microgrid through an exhaustive simulation in MATLAB/SIMULINK platform.

Keywords: Power quality (PQ); unified power quality conditioner (UPQC); active power filter (APF); adaptive neuro fuzzy inference system (ANFIS); microgrid.

1. Introduction

Utility connected microgrid system is evolved as the future power distribution system. In general microgrid is integration of AC and DC grids, various distributed generators (DG), renewable energy sources, energy storage system, power electronic converters and control strategies [1]. Major tasks must be carried out on integration of microgrid and power distribution grid are the management of the optimal power flow between AC/DC grid and

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compensation of power quality issues [2]. The power quality issues of grid connected microgrid system are broadly classified into utility related PQ problems and customer related PQ problems. The utility related PQ problems are voltage sag/swell, flicker, notches, unbalanced source, interruption and customer related PQ problems such as total harmonic distortion (THD), unbalanced load, reactive power demand and lagging power factor [3-5]. Among all PQ distortions, serious PQ distortion occurs in the utility side is voltage drop and in customer side is harmonic distortion. These PQ deformations lead to decrease in the efficiency of power system network and reduce the life span of equipment connected. Recent research proves that the UPQC is an affordable custom power device employed at the point of common coupling (PCC) to protect both utility and customer from PQ distortion [6-8].

The UPQC device is combination of series and shunt active power filter (APF) with a common DC link capacitor. The compensation capability of UPQC device is determined by the optimum regulation of DC link voltage. In traditional UPQC device, the regulation of DC link voltage is achieved by the conventional PI controller. The conventional PI controller block requires linear mathematical expressions which fail to regulate DC link voltage under high voltage drop and dynamic operating conditions [9-11]. And also constant reference value is used to regulate actual DC link voltage for all operating conditions. Under voltage drop conditions, constant reference DC link voltage resulted in high power drop across the load terminal [12].

An adaptive neuro fuzzy inference system (ANFIS) is a powerful tool that integrates both fuzzy system and neural network learning. Unlike conventional controller [13], ANFIS has the ability to learn, remember and take decision. In the proposed work, ANFIS is trained to operate as reference DC link voltage estimator and DC link voltage controller. The construction of UPQC device connected to utility-microgrid system is discussed in the next section.

**Nomenclature**

- APF: active power filter
- ANFIS: adaptive neuro fuzzy inference
- MG: microgrid system
- MGU: utility connected microgrid system
- PQ: power quality
- PCC: point of common coupling
- UPQC: unified power quality conditioner
- VSI: voltage source inverter

Fig. 1. Basic configuration of microgrid with UPQC device
2. Construction of UPQC device based utility connected microgrid

Fig. 1 shows basic configuration of utility connected microgrid with UPQC device. The test system consists of microgrid, utility and UPQC device.

2.1. Microgrid

Microgrid is the combination of multiple alternative energy sources connected to a common bus bar. In the test case, energy sources are wind power plant, PV plant and battery source. The entire energy sources are connected to DC bus bar. The power generated by wind power plant is converted to DC using power rectifier [3].

2.2. Utility

In utility side, AC bus bar is connected to the distribution transformer. The DC bus bar is connected to the AC bus bar through power inverter. The critical load is connected to AC bus bar through UPQC device [8].

2.3. UPQC device

The power circuit of proposed UPQC topology is shown in Fig. 2. The UPQC topology is designed from the two voltage source inverters (VSI) with a common DC link capacitor (C_{dc})[1], [11]. One VSI is connected in series with the source through coupling transformer which functions as the series APF [7]. The series APF is the responsible for compensating the utility related PQ distortion at point of common coupling (PCC) [5]. The other VSI is connected in parallel between the series APF and the load which operates as the shunt APF [10]. The shunt APF is responsible for compensating the customer related power quality problems and regulates the DC link voltage. In proposed topology, shunt passive series capacitor (C_{sh}) plays important role on supporting shunt APF. In load side, passive series capacitor (C_{L}) supports regulation of reactive power flow in the topology.

3. Modelling of control technique

The main objective of the proposed control technique is to regulate both series and shunt APF. Hence the control technique is broadly classified into the series and shunt control techniques [5].
3.1. Series Adaptive Control Technique

The series control technique is designed to regulate rated load. The block diagram of series control technique is shown in Fig. 3.A. the series control technique regulates load voltage using following process such as reference signal generation, capture of utility side PQ distortions and generation of pulses for series VSI. The reference load voltage is generated from the product of rated load voltage magnitude ($V_{Lm}$) and three phase unit sine signal ($U_{abc}$) and it is give in (1). The utility side PQ distortions are captured from the difference of reference and actual load voltage and as given in (2). The pulses for series VSI are generated from the utility side disturbances using hysteresis controller.

$$
\begin{align*}
V_{Lm}^* &= V_{Lm} \sin(\omega t) \\
V_{Lb}^* &= V_{Lm} \sin(\omega t + 120^\circ) \\
V_{Lc}^* &= V_{Lm} \sin(\omega t - 120^\circ)
\end{align*}
$$

(1)

$$
\begin{align*}
V_{Ca} &= V_{La}^* - V_{La} \\
V_{Cb} &= V_{Lb}^* - V_{Lb} \\
V_{Cc} &= V_{Lc}^* - V_{Lc}
\end{align*}
$$

(2)

3.2. Shunt Control Technique

The proposed shunt control technique is designed to regulate source current and DC link voltage ($V_{dc}$). The block diagram of the shunt control technique is shown in Fig. 3.B. the objective function the shunt APF is achieved by the following process such as reference DC link voltage ($V_{dc}^*$) estimation, $V_{dc}$ controller, reference source current generation, capture of customer side PQ distortions and generation of pulses for shunt VSI. In the proposed technique, ANFIS is trained to estimate $V_{dc}^*$ and $V_{dc}$ controller. The ANFIS controller is trained to generate fundamental real component of source current. The reference source current is the product of fundamental real component of source current and three phase unit sine vector and it is given in (3). The customer side PQ distortion is captured from difference of reference and actual source current and as given in (4). And pulses for shunt VSI is generated from the customer related PQ distortion using hysteresis current controller.

$$
\begin{align*}
I_{La}^* &= I_1 \sin(\omega t) \\
I_{Lb}^* &= I_1 \sin(\omega t + 120^\circ) \\
I_{Lc}^* &= I_1 \sin(\omega t - 120^\circ)
\end{align*}
$$

(3)
\[
\begin{bmatrix}
I_{Ca} \\
I_{Cb} \\
I_{Cc}
\end{bmatrix} -
\begin{bmatrix}
I_{sa}^* \\
I_{sb}^* \\
I_{sc}^*
\end{bmatrix} =
\begin{bmatrix}
I_{sa} \\
I_{sb} \\
I_{sc}
\end{bmatrix}
\] (4)

### 3.3. Power Flow Analysis

After connecting UPQC, the source voltage and current are found to be in phase with each other and free from harmonic distortions and as given in (5). The series and shunt APF parameters are derived in (6) and (7).

\[
V_s < 0, I_s < 0, \text{Since } \phi_s = 0, \begin{bmatrix}
P_s \\
Q_s
\end{bmatrix} = \begin{bmatrix}
V_s I_s \\
0
\end{bmatrix}
\] (5)

\[
V_{s} < 0 = V_{r} < 0 - V_{i} < 0; \begin{bmatrix}
P_{sr} \\
Q_{sr}
\end{bmatrix} = \begin{bmatrix}
V_{r} I_{r} \cos(\phi_{sr}) \\
V_{r} I_{r} \sin(\phi_{sr})
\end{bmatrix}
\] (6)

\[
I_{sh} < 0, \phi_{sh} = I_{h} < 0, \phi_{h} - I_{i} < 0; \begin{bmatrix}
P_{sh} \\
Q_{sh}
\end{bmatrix} = \begin{bmatrix}
V_{i} I_{i} \cos(\phi_{sh}) \\
V_{i} I_{i} \sin(\phi_{sh})
\end{bmatrix}
\] (7)

Hence after compensation, the load real and load reactive powers are computed as follows.

\[
P_{L} = V_{L} I_{i} \left(1 - \cos(\phi_{sr})\right) + V_{L} I_{r} \left(\cos(\phi_{sr}) - \cos(\phi_{sh})\right) - V_{r} I_{s} \cos(\phi_{sh})
\] (8)

\[
Q_{L} = V_{L} I_{i} \left(\sin(\phi_{sr}) - \sin(\phi_{sh})\right) + V_{L} I_{r} \sin(\phi_{sh}) - V_{r} I_{s} \sin(\phi_{sr})
\] (9)

### 4. ANFIS learning procedure

An ANFIS is a hybrid artificial intelligence technique with the ability to formulate mapping from training and target data using adaptive neural network and fuzzy logic control. The flow chart for ANFIS training procedure is elaborately discussed in [13]. In general, ANFIS architecture with two inputs \((x, y)\), two rules \((r1, r2)\) and five layered feed forward artificial neural network consists of adaptive (square) and non-adaptive (circle) nodes with single output is discussed in [9]. The hybrid learning rule combines gradient descent method [12] and least square estimation (LSE). The adaptive network under LSE learning algorithm assumed has only one output. In hybrid learning algorithm, the back propagation learning algorithm adopted to tune hidden layer parameter and output layer parameter is identified by applying LSE technique. The hybrid learning algorithm not only reduced search space dimension in the gradient method, but also considerably minimized the convergence time. Simulation result for ANFIS tracking is shown in Fig. 4. From the result, it is observed that the ANFIS output is optimally tracking training data.

![Result for tracking ANFIS output and training data](image)
5. Simulation results and discussion

The compensation capability of proposed ANFIS UPQC is examined for two case studies such as utility system (U) and utility connected Microgrid system (MGU) using MATLAB/ SIMULINK environment.

![Simulation results and discussion](image)

5.1. Estimation of reference DC link voltage using ANFIS

Fig. 5.(a). shows the simulation response of source voltage magnitude in per unit (PU). The simulation Estimation of \( V_{dc}^{*} \) using ANFIS for trained and untrained operating conditions is shown in Fig. 5.(b). ANFIS is trained to estimate \( V_{dc}^{*} \) from source voltage magnitude and power factor. The trained operating conditions are taken as voltage drop (0%, 10%, 20%, 30%, 40% to 100%)and untrained operating conditions are considered as voltage drop (5%, 15%, 25%, 35% to 95%). In Fig. 5.(a). The trained operation conditions are given between 0 sec to 1.1 secand untrained operation conditions are taken between 1.1 sec to 2.6 sec and also notch (2 PU) is introduced at 2.4 sec. From the obtained result, it is observed that ANFIS is optimally estimates \( V_{dc}^{*} \) under both trained and untrained operating conditions.

5.2. Investigation on DC link voltage regulation and power drop

In this section, \( V_{dc} \) regulation and power drop is analyzed for both U and MGU. The simulation result for \( V_{dc} \) regulation using ANFIS for voltage drop on U and MGU is shown in Fig. 6(a). From the response, it is found that the \( V_{dc} \)is optimally regulated by trained ANFIS under both utility and microgrid disturbances. The power drop across the load terminal is analyzed for without and with UPQC and correspond result is highlighted in Fig. 6(b). For without UPQC device, power drop across the load terminal increases with increase in voltage drop whereas with UPQC device, power drop is maintained approximately near to zero. Hence this investigation proves that ANFIS UPQC optimally works under disturbances occur in U and MGU.

![Simulation results and discussion](image)

5.3. Compensation of PQ distortion originated in MGU

In this section, the proposed ANFIS-UPQC device is installed to protect the load from PQ distortion originated in
MGU and corresponding simulation results are highlighted in Fig 7(a) to Fig. 7(f). The source, load and compensation voltage are shown in Fig. 7.(a), (b) and (c) respectively and the source, load and compensation current are shown in Fig. 7. (d), (e) and (f) respectively. The operating condition taken for this investigation is utility side disturbances and microgrid side disturbances. In utility side disturbance are microgrid is connected at 0.3 sec. after microgrid connected, 1.2% of THD is generated in source voltage and unbalanced source is connected between 0.35 sec and 0.4 sec. in microgrid side disturbances are wind power plant disturbances causes notch at 0.48 sec and source voltage sag is generated by sudden discharge of battery storage between 0.5 sec and 0.55 sec shown in source voltage. During voltage related power quality problems, series active power filter plays vital role on compensation and maintains rated load voltage across load shown in Fig. 7. (b). During current related power quality problems, shunt active power filter plays major part such that harmonic distortions and reactive power demand are mitigated on the source side. Comparative analysis of compensation of PQ distortion using ANFIS-UPQC device for Utility system (U) and utility connected microgrid system (MGU). From Table 1, it is observed that voltage and power drop is minimized with the support of the MGU. And also THD compensation is successively achieved by the MGU. Hence this investigation proves that the proposed ANFIS-UPQC device has ability to protected load form PQ distortion originated from integration of utility and microgrid system.
Table 1. Comparative analysis of PQ compensation using ANFIS-UPQC

<table>
<thead>
<tr>
<th>Sag (%)</th>
<th>Voltage Drop (%)</th>
<th>Power Drop (%)</th>
<th>THD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U MGU</td>
<td>U MGU</td>
<td>MGU MGU</td>
</tr>
<tr>
<td>0</td>
<td>0.3</td>
<td>0.1</td>
<td>0.8</td>
</tr>
<tr>
<td>20</td>
<td>1.2</td>
<td>0.4</td>
<td>2.2</td>
</tr>
<tr>
<td>40</td>
<td>8.1</td>
<td>0.9</td>
<td>15</td>
</tr>
<tr>
<td>60</td>
<td>30</td>
<td>2.3</td>
<td>35</td>
</tr>
<tr>
<td>80</td>
<td>70</td>
<td>7.5</td>
<td>75</td>
</tr>
</tbody>
</table>

6. Conclusion

An ANFIS based adaptive control strategy is proposed in this paper for the effective compensation of PQ distortion originated by integration of microgrid and power distribution system using UPQC device. The performance of the proposed UPQC device is investigated for both utility side disturbances and microgrid side disturbances. The advantage of sharing the load reactive power demand by the series and shunt APF is also addressed in this paper. The real and reactive power flow is also analyzed in this paper. From the analysis, it is found that the ANFIS-UPQC fails to compensate PQ distortion over 50% sag for utility alone power distribution system. For microgrid connected power distribution system, an ANFIS-UPQC device successfully compensates PQ distortion up to 90% Sag. From the overall investigation, it is proved that the proposed ANFIS-UPQC device has better compensation capability for the management of inherit power quality issues.

References