Advanced approach to compensation of reactive power in isolated arctics electrical supply systems

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Abstract: Compensation of consumed reactive power is an important task for the electric power industry. In real conditions, reactive power is constantly changing. In order to achieve good compensation, it is necessary in a timely manner to adjust the reactive power of the compensating devices. We suggest advanced compensation system for isolated electrical grids in the Arctic. In this system power adjustment of the compensating device is made with expected consumption of reactive power. Consumption is forecast by the measured values of reactive power using a Taylor series.

1. Introduction

Currently, the active development of the Arctic territories is underway. The centralized supply of electricity to these remote areas is costly. In isolated electrical grids in the Arctic, using of the latest reactive power compensation devices (FACTS, STC) is problematic [1-3]. In this regard, the authors have proposed a new approach - advanced compensation of reactive power.

The electrical power system consists of four components: production, transmission, distribution and consumer (Figure 1).

![Figure 1. Electricity transmission sequence](image)

Each of these components, by their characteristics, impacts on operability of the electric power system and on supplied electricity quality [4-7]. For the rational electricity using, it is required to provide cost-effective methods for its generation, transmission and distribution with minimal losses. For this, it is necessary to exclude from the electrical networks the factors leading to the occurrence of losses, in particular to compensate for reactive power.
2. The main principles of the approach

Traditionally, the power of the compensating device $Q_{\text{comp}}$ remains constant and numerically (in modulus) equal to the calculated reactive power $Q_{\text{calc}}$, but opposite sign [8-12]. Generally industrial users consume inductive reactive power, thus, compensating device must consume reactive capacitive power. The disadvantage of this method is that the actual reactive power of consumer $Q_{\text{cons}}$ does not remain constant over time. If reactive power of consumer $Q_{\text{cons}}$ differs from calculated reactive power $Q_{\text{calc}}$, then the condition of complete compensation is violated and reactive current will flow from the supply network, which is accompanied by losses of active power in the supply network.

A more flexible way is adjustable step reactive power compensation (SRPC) [13-15]. To do this, at regular intervals, the consumed reactive power $Q_{\text{cons}}$ is determined and on this basis the compensating reactive power module $|Q_{\text{comp}}| = Q_{\text{cons}}$ is set. This method assumes that $Q_{\text{cons}}(t)$ changes over time strictly according to a stepwise law and restructuring of power $Q_{\text{cons}}$ is exactly at the moment of $Q_{\text{cons}}$ transition from one stage to another. The last requirement is technically difficult to fulfill [16-18].

Let us explain what has been said by the time diagrams of the work of the SRPC. Consider the ideal case of stepwise reactive power compensation (Fig. 2).

As seen in Fig. 2, if the change in reactive power of consumer and the compensator occurs synchronously, their algebraic sum is equal to zero. Obviously, a somewhat different picture is observed in practice.

Figure 3 shows a real case of step compensation.

As seen from diagram $Q_{\text{cons}}(t)$ that in some time intervals the compensation is violated, and consumed reactive power of one sign or another from the supply network, which is accompanied by losses of active power in the supply wires.

In the general case, the dependence $Q_{\text{cons}}(t)$ with a large number of reactive power consumers is a fairly smooth function that differs from the step function [19, 20].

![Figure 2. The ideal case for step compensation](image-url)
In fig. 2:

\[ Q_{\text{cons}}(t) \] - consumed reactive power;
\[ Q_{\text{comp}}(t) \] - adjustable reactive power of a step compensator;
\[ Q_z(t) = Q_{\text{cons}}(t) + Q_{\text{comp}}(t) \] - algebraic sum of reactive powers of consumed and compensating;
\[ Q_{\text{cons}}(t_0), Q_{\text{cons}}(t_1), Q_{\text{cons}}(t_2) \] - respectively the values of consumed reactive energy at the moments of time \( t_0, t_1, t_2 \);
\[ Q_{\text{comp}}(t_0), Q_{\text{comp}}(t_1), Q_{\text{comp}}(t_2) \] - respectively the values of the reactive power of the compensator at the moments of time \( t_0, t_1, t_2 \).

![Diagram showing consumed and compensating reactive powers](image)

Figure 3. The real case for step compensation

3. Problem statement and its solution

The problem and solve it way we consider using the diagrams shown in Fig. 4 [20].

In fig. 4:

\( \Delta t \) - measurement interval;
\( Q(t_0), Q(t_1), Q(t_2) \) - the values \( Q_{\text{cons}}(t) \) at times \( t=t_0, t=t_1, t=t_2 \) obtained experimentally;
\( Q_{\text{cons}}(t_0 + \frac{1}{2} \Delta t) \) - the values \( Q_{\text{cons}}(t) \) obtained theoretically (future value);
\( Q_z(t) \) - the resulting power in the interval \([t_0, t_1]\).

As a result of the current measurements of consumed reactive power, we obtained the values \( Q_{\text{cons}}(t_1), Q_{\text{cons}}(t_2), Q_{\text{cons}}(t_0) \) at points \( t=t_2, t=t_1, t=t_0 \) separated by time interval \( \Delta t \). The required value of the regulated compensating power must be set in advance on the basis of these data, take it to the module equal power \( Q_{\text{cons}}(t) \) at the time, being in the middle of the interval from \( t_0 \) to \( t_1 \).

To determine \( Q_{\text{cons}}(t_0 + \frac{1}{2} \Delta t) \), we use the expansion of the function \( Q_{\text{cons}}(t) \) in the Taylor series, from which it follows that if we know the value \( Q_{\text{cons}}(t=t_0) \), the value of this function at the point \( t = t_0 + \frac{1}{2} \Delta t \) is determined as follows:

\[
Q_{\text{cons}}(t_0 + \frac{1}{2} \Delta t) = Q_{\text{cons}}(t_0) + Q'_{\text{cons}}(t_0) \left( \frac{1}{2} \Delta t \right) + \frac{1}{2} Q''_{\text{cons}}(t_0) \left( \frac{1}{2} \Delta t \right)^2
\]  

(1)
Derivatives are determined by the following approximate expressions:

\[
Q'_\text{cons}(t_0) = \frac{Q_{\text{cons}}(t_0) - Q_{\text{cons}}(t_{-1})}{\Delta t} \quad (2)
\]

\[
Q'_\text{cons}(t_0) = \frac{Q_{\text{cons}}(t_{-1}) - Q_{\text{cons}}(t_{-2})}{\Delta t} \quad (3)
\]

\[
Q''_{\text{cons}}(t_0) = \frac{Q'_\text{cons}(t_0) - Q'_\text{cons}(t_{-1})}{\Delta t} \quad (4)
\]

In Fig.4 shows the value obtained in this way \( Q_{\text{cons}}(t_0 + \frac{1}{2} \Delta t) \), and, accordingly:
\[ |Q_{\text{comp}}| (t = t_0) = Q_{\text{comp}} \left( t_0 + \frac{1}{2} \Delta t \right) \]  

(5)

The Fig. 4 shows that resulting reactive power close to zero. Similarly, the procedure is repeated for each subsequent point in time.

The device operates as follows (Fig. 5). Reactive power meter 1 determines the value of the consumed by the user \( R_{\text{cons}} \) after a time interval \( \Delta t \). Computing device 2 stores the values: \( Q_{\text{cons}}(t_1), Q_{\text{cons}}(t_2), Q_{\text{cons}}(t_0) \), and defines derivatives:

\[
\frac{d Q_{\text{cons}}(t_{-1})}{dt} = \frac{Q_{\text{cons}}(t_0) - Q_{\text{cons}}(t_{-1})}{\Delta t} 
\]  

(6)

\[
\frac{d Q_{\text{cons}}(t_{-2})}{dt} = \frac{Q_{\text{cons}}(t_{-1}) - Q_{\text{cons}}(t_{-2})}{\Delta t} 
\]  

(7)

\[
\frac{d^2 Q_{\text{cons}}}{dt^2} = \frac{\frac{d Q_{\text{cons}}(t_{-1})}{dt} - \frac{d Q_{\text{cons}}(t_{-2})}{dt}}{\Delta t} 
\]  

(8)

Figure 5. Simplified block diagram of the device of Advance compensation of reactive power (1-reactive power meter; 2-computing device; 3-logic unit; 4-control device; 5-additional reactive power meter)

And the predicted value of power \( Q_{\text{cons}} \left( t_0 + \frac{1}{2} \Delta t \right) \) in the middle of the interval \([t_0, t_1]\), and the value of the compensating power \( |Q_{\text{comp}}| (t = t_0) = Q_{\text{cons}} \left( t_0 + \frac{1}{2} \Delta t \right) \).

Logical device 3 generated signals that control the control device 4, to obtain the necessary compensating reactive power by changing the total power capacitor C. The additional reactive power
meter 5 can, if necessary, to measure the reactive power consumed by the compensated installation from the network.

This meter can be combined with the reactive energy meter. Additional power meter and reactive energy meter can quantify the effectiveness of SCRP.

It should make the following remark. Implementing a distributed filtering and advanced compensation will require substantial financial costs. The economic effect would indirectly emerge from more efficient operation of all consumers.

The advanced compensation algorithm is shown in Fig. 6

```
Q_{cons}

R_{cons} X_{cons}

\frac{dQ_{cons}(t)}{dt}

Q_{cons}(t_0 + \frac{t}{2})

Q_{comp}

Q_{cons} \leq Q_{opt}

NO YES

EXIT
```

**Figure 6.** The flow-chart of algorithm for advanced compensation of consumed Reactive Power

4. Conclusions

The authors suggested an advanced compensation consumed reactive power for isolated electrical networks in the Arctic.

Known methods for reactive power compensation, based on the regulation of power compensating devices on the current consumption of reactive power are inconclusive in the case of step and the smooth change of reactive power consumption.

The proposed method of Advance compensation reactive power is a further development of active compensation method, based on known mathematical extrapolation method, for example, using a Taylor series.

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