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Development of a novel method for optimal use of a newly designed reactive power control relay

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ABSTRACT

In this study, a new method for a reactive power control relay is developed. The method reduces the switching number of contactors, resulting in less active energy losses in the system operated by the reactive power control. The method consists of three main parts. The first part minimizes the delay time that is required to discharge capacitors. The second part develops a new algorithm in order to optimally select the capacitor value, which compensates the measured reactive power value of the system. The third part uses the Goertzel algorithm instead of Fast Fourier Transformation (FFT) in order to perform harmonic analysis and power calculations of the voltage and current samples obtained from the system. The use of the Goertzel algorithm results in less trigonometric equations and faster calculation time. An electronic circuit that implements the above algorithm is also developed. Theoretical calculations and experimental results are presented.

1. Introduction

Most industrial loads have lagging power factor; that is, they absorb reactive power [1,2]. Large amount of reactive power consumption causes extra power losses and voltage stability problems in power systems [3,4]. Reactive power compensation is usually the most effective way of improving the real power transfer capability of the generation and distribution system. This inductive reactive current should be compensated by means of a power factor controller with the related capacitor units [5–9]. Reactive power compensation is automatically achieved with reactive power control relay. Shunt capacitors are switched on and off sequentially during this process [4]. When a capacitor is switched off, it is necessary to ensure that it has been fully-discharged before it is switched on again. This is required for efficient working of the control relay. This is called delay time or discharge time. The discharge time can be set between 15 and 300 s [8,10,11].

Although there are many type of compensation systems, the centralized system is used most commonly. In this system, capacitors are switched on by contactors. Selection of contactors depends on breaking currents and the amount of switchings number [11]. In classic relay, capacitors are switched on and off according to the certain switching programs [10]. Until all capacitors are switched on, systems remain as discompensated. However, during this transition time period, many switchings might occur. This means that, since the current passing through the line has an inductive character, active power losses are still high during the transition.

Although many researchers have been studying on reactive power compensation, the compensation relays in particular are mainly developed by industrial companies. This work emphasizes improvements on delay time and switching program of a compensation relay. Additionally, the parameters of active and reactive power are measured and calculated by using Goertzel algorithm. The parameters are applied to reactive power control relay for the first time.

2. Power system design

Reactive power compensation is provided by stationary shunt capacitors. The compensation system may be installed individually, centrally or a type of group. The schematic diagram of centralized reactive power system is shown Fig. 1 [4].

A typical low voltage reactive power compensation system mainly consists of a control relay, compensating capacitors and contactors. Line voltage is connected to the control relay directly while the current is connected to the controller (control relay) via a current transformer. Power factor control relay is used for measuring and controlling the power factor in applications that utilizes central reactive power compensation [1,4]. The control relay obtains voltage and current samples continuously from the

Abbreviations: DFT, discrete fourier transform; FFT, Fast Fourier Transform; LCD, liquid crystal display; RAM, read only memory; ADC, analog/digital converter.

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Nomenclature

$v(t)$	power source voltage	f	frequency
$i(t)$	power source current	a	constant
γ	harmonic levels	b	constant
P	active power	α	constant
Q	reactive power	β	constant
S	apparent power		

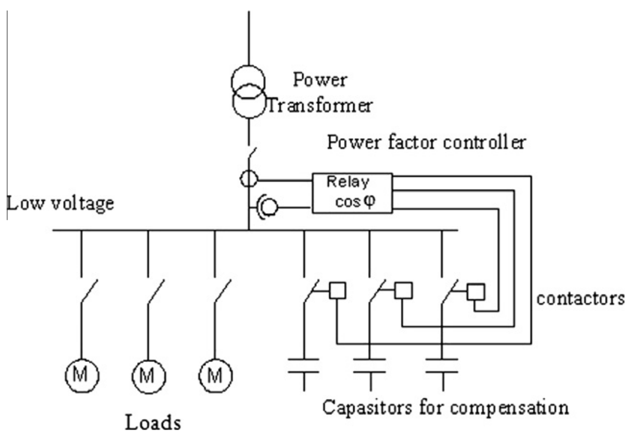

Fig. 1. Schematic diagram of centralized reactive power compensation system.

load. These samples are used to calculate active and reactive power portions of load. If the reactive power portion exceeds certain threshold values, a switching action take place at the switching outputs of the relay. A contact of the reactive power control relay is closed according to a preprogrammed time delay. This causes relay to switch a capacitor onto the load. On the other hand, if at any time, the inductive reactive power portion of the load becomes less than the total capacitor value switched onto the system, some capacitors are switched off the line to recompensate the system [4,10].

3. Conventional reactive power control relay

Conventionally, reactive power controller measures continuously the reactive power consumption of the load. In order to maintain a preset power factor, it connects or disconnects capacitor into system [10]. The hardware portion of the controller consists of the following main circuits: Measurement circuit, power supply board, control and logic board, output relay circuit, and signaling and data input circuit [10,12].

The controller measures continuously line voltage and line current in order to calculate reactive power demand of load. It then selects and sends switching signals in relation to the amount of compensation needed to external capacitor switching circuits that will dynamically switch in the appropriate capacitor banks for the proper amount of reactive power compensation [13,14]. All necessary preset values are entered to the relay. All output data such as alert information, power component can be seen on the LCD display screen of the controller. User can also set desired initial values. Before working relay, some parameters that are specific to the application have to be set in the controller. Some features of the controller that can be set by the user are switching sequence, switching program, current transformer turn ratio setting (c/k where c is the power of the first capacitor group and k defines the current transformer ratio), regulation region, target power factor (cos φ), etc. [10,11].

There are two different switching programs in the conventional relay.

- *Rotational switching*: This mode switches capacitors into the system equal time periods and sequential manner. This ensures that all contactors have approximately same and maximum life time.
- *Linear switching*: This mode always starts the compensation from the same capacitor and uses the remaining ones as needed [10].

4. Newly designed reactive power control relay

Conventional controllers use a microprocessor and other necessary data acquisition peripherals to perform reactive power compensation. Using a faster microprocessor can speed up working of conventional relay, however this does not effect overall operating logic of the controller [15,16]. This study proposes several enhancements on operational logic of a conventional reactive power controller. These enhancements are given below:

1. A specific feature of a reactive power controller is that when a capacitor needs to be added to the system, the controller has to wait a certain time called discharged time before performing this action. However, during the discharge time, the system remains as uncompensated and active power losses continues to exist.
2. In conventional relays, when controller performs compensation, it switches on and off capacitors according to specific switching programs. These programs has to be loaded into the controllers memory in advance, and they specify specific combinations in which the capacitor are switched on and off to system accordingly [10,11]. Yet, another feature of the conventional controllers is that it switches on and off capacitors to the system one at a time. However, until the system becomes fully compensated, a conventional controller cannot avoid active power losses of the system. Another disadvantage of using prespecified switching actions (programs) is that the controller performs the compensation on the system based on trial and error. This means that the controller switches on a capacitor, then looks at the system to see whether it becomes compensated or not. If it is not compensated, then it switches on another capacitor or so on based on the actions defined in the prespecified switching program [10]. These trial and errors may cause more switchings of capacitors that it might optimally be needed. As a result, the contactor and capacitor life time are reduced.
3. In conventional relay, DFT and FFT algorithms are used for harmonic analysis. However, DFT requires many trigonometric equations to be taken into consideration [13].

In this study, we develop a new method that controls the working of a conventional reactive power controller in an optimal way both in terms of number of switchings of capacitors and minimization of the needs to wait for the discharge times. As a result, the