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Original Article

Design an Automatic Stepless Power Factor Correction System based on PID Controller

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Abstract - *The study proposes the automatic stepless reactive power compensation system. This system is expected to replace the existing systems due to its obvious improvements. PID controller in PLC is applied considered as an effective method for controlling this system. PID controller is applied to SVC power factor correction.*

Keywords - *PLC, PID, SVC, Thyristor Controlled Reactor, real-time.*

I. INTRODUCTION

Electrical devices, such as transformers, motors, or converters, need magnetizing power or current to work properly. This power is not transformed into heat but oscillates between the load and the source. It is called reactive power. The power factor (PF) cosφ is defined as a ratio between the active power P and the apparent power S as follows: $\cos\varphi = P/S$

When $\cos\varphi = 1$ named unity PF, no reactive power flows in the line. If reactive power is positive, the PF is leading. On the other hand, if reactive power is negative, the PF is lagging. In general, it is required that the loads connected to the public networks should be operated at the points close to the unity PF. The value of the leading PF is about 0.95, considered as a minimum. Any deviations from this value mean additional fees for the customer. In order to remain the PF within permissible limits, countermeasures must be adopted, meaning a power factor correction.

Basically, there are two major types of PF correction - series and shunt compensation:

Series compensation is used due to voltage drops at the end of long power transmission lines. Simply, there are capacitor banks connected in series with the line. This improves the voltage at the end of the line, and also short-circuit power is increased additionally [6].

Shunt compensation is carried out by a shunt-connected compensating device. The required reactive power is generated by a shunt-connected capacitor or an inductor. Thus, no or just little reactive power is drawn from the main source. Fig. 1 shows the basic principle of the PF correction using the shunt-connected compensating device (K). The reactive powers of the main source and the compensating device K (Qcom) are brought to the main bus to cover the required load reactive power (Q). Generally, the reactive power drawn from the main source has been decreased, and the low PF of the load is corrected.

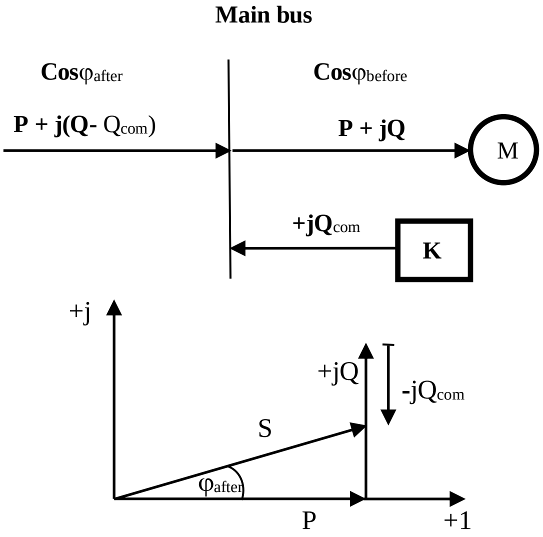

Fig. 1 Power factor correction

The existing reactive power compensation systems in the network appear several drawbacks, especially the incorrect compensation and the redundancy in multilevel compensation systems. Designing a correct reactive power compensation system is the aim of this paper.

II. MAIN CONTENT

A. Methods of Power Factor Correction

a) Dynamic Capacitor Banks

The power factor regulator is designed to optimize the control of the reactive power compensation. Reactive power compensation is achieved by measuring the reactive power of the system continuously and then compensated by the switching of capacitor banks. This stepping switching, in some cases, leads to redundant compensation, causing higher load voltage.

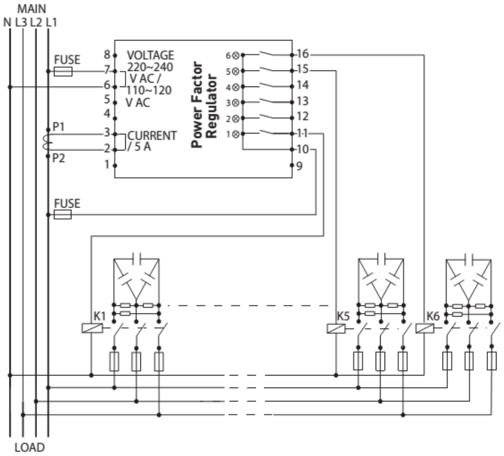

Fig. 2 Power factor correction using Dynamic capacitor banks

b) Static VAR Compensator

A static VAR compensator is a set of electrical devices for providing fast-acting reactive power on high-voltage electricity transmission networks.[1][2] SVCs are a part of the Flexible AC transmission system [3][4] used to family devices, regulating voltage, power factor, harmonics, and stabilizing the system. A static VAR compensator does not have significant moving parts (other than internal switchgear). Prior to the invention of the SVC, power factor compensation was the preserve of large rotating machines such as synchronous condensers or switched capacitor banks.[5]

The SVC is an automated impedance matching device designed to bring the system closer to the unity power factor. SVCs are used in two main situations:

Connected to the power system to regulate the transmission voltage ("Transmission SVC")

Connected near large industrial loads to improve power quality ("Industrial SVC")

In transmission applications, the SVC is used to regulate the grid voltage. If the power system's reactive load is capacitive (leading), the SVC will use thyristor-controlled reactors to consume VARs from the system, lowering the system voltage. Under inductive (lagging) conditions, the capacitor banks are automatically switched in, thus providing a higher system voltage. By connecting the thyristor-controlled reactor, which is continuously variable, along with a capacitor bank step, the net result is continuously variable, leading or lagging power.

In industrial applications, SVCs are typically placed with near high and rapidly varying loads, such as arc furnaces, where they can smooth flicker voltage.[1][6]

c) Thyristor Controlled Reactor

The fundamental component of the SVC is the thyristor-controlled reactor (TCR). TCR is thyristor controlled inductor whose effective reactance is varied in a continuous manner by partial-conduction control of the thyristor valve or the triac valve [4]. It contains a thyristor valve and an inductor connected in series. The current within the coil can be continuously controlled by the thyristor firing angle α(Fig. 2). It is the time delay between the supply voltage peak value and the firing pulse as the thyristor is triggered. When α= 0, the thyristor valve is switched on completely, and the current reaches the highest value. When α = 90°, the thyristor valve is switched off, and no current flows. According to this assumption, the inductive reactive current is easily controlled by changing the value of α. σ is the conduction interval [5]. It is the time period in which the thyristor is in the conductive state.

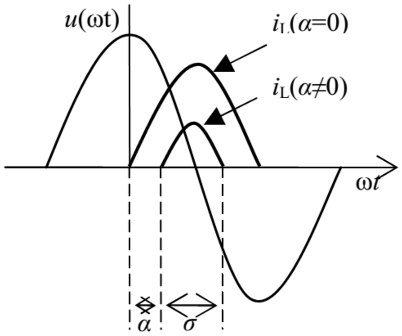

Fig. 3 Voltage and current time courses depending on firing angle α

d) Single-phase SVC

A single-phase SVC consists of a shunt connected to the TCR branch and the fixed capacitor (FC) (Fig. 3). In comparison, the reactive power of FC is half of the maximum reactive power of TCR. Thus, the output SVC reactive power is controlled in both directions – from maximum var power generation to maximum var power absorption. It means both leading and lagging power factors are corrected.

The proposed SVC model is based on a three-phase FC-TCR delta-connected arrangement [7], [8]. SVC is designed to operate in such a way that reactive power is controlled in each phase independently and automatically adaptable to the load conditions.

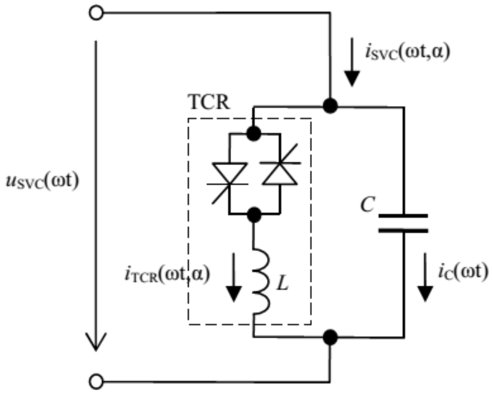

Fig. 4 Single-phase SVC

B. Real-time SVC power factor correction Control

a) PID Algorithm

Parallel structure including three-term functionality and a typical structure of a PID control system is shown in Fig.5. A mathematical description of the PID controller is given in the following Equations (1, 2):

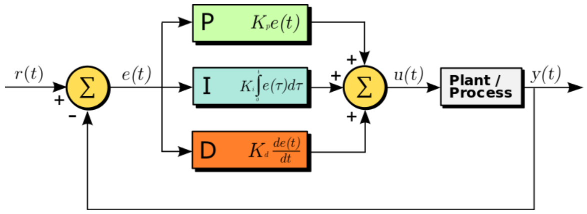

Fig.5 PID controller

$$u(t)=K_Pe(t)+K_I\int_0^t e(\tau)d\tau+K_D\frac{de(t)}{dt}$$

Where $u(t)$ is the control signal, and $e(t)$ is the error signal? The reference value is called the SetPoint. The difference between the Process Variable (PV) and the SetPoint (SP) is the error signal e(t): $e(t)=r(t)-y(t)=PV-SP$. K_P , $K_I=\frac{K_P}{T_I}$ and $K_D=K_P*T_D$ are the proportional gain, the integral gain, and the derivative gain, respectively.

1) Proportional Term

The proportional term provides an overall control action proportional to the error signal through the all-pass gain factor. Increasing the proportional gain is the cause of decreasing the error and increasing the oscillation of the system. Tuning theory and practical implementation shows that the proportional term should influence the output.

2) Integral Term

The integral term reduces steady-state errors through low-frequency compensation. The integral term is proportional to the integral of the error. As it integrates the error over time, it causes the overshoot of the present value to the SetPoint value.

3) Derivative Term

The derivative term improves transient response through high-frequency compensation. The rate of error changes is the contribution of the derivative term. It gives additional control by predicting errors and future behavior of the system.

Due to its variable impact on system stability, derivative action is rarely used in practice. The pure derivative action is never used because of the derivative kick produced in the control signal for a step input and to the undesirable noise amplification. It is usually replaced by a first-order low pass filter.

b) PID Algorithm for SVC

There is a load connected at the end of the line, and it consumes active power P and reactive power Q_L. The compensating power of SVC is Q_{SVC}. Variables P and Q are actual values of active and reactive power, respectively, that are drawn from the grid.

In general, the control unit regulates the compensating reactive power of SVC (QSVC) automatically by three PID regulators and five basic stages:

1. Firstly, the actual active P and reactive power Q in phases are calculated by mean values of instantaneous voltage u and current i.
2. Secondly, a reference reactive power Q_{ref} is computed from a desired power factor $\cos\varphi_{ref}$ in HMI TD200 and actual active power P.
3. Q is compared with $Q_{ref,}$ and the error ΔQ continues to go to the PID controller.
4. PID regulates the deviation between the measured reactive power and the desired value in order to reduce the difference to zero. It is implemented by alternating the firing angles αof the thyristors.
5. At last, a firing-pulses generator (FPG) is needed. This unit generates the switching pulses (SP) to trigger the thyristors on.

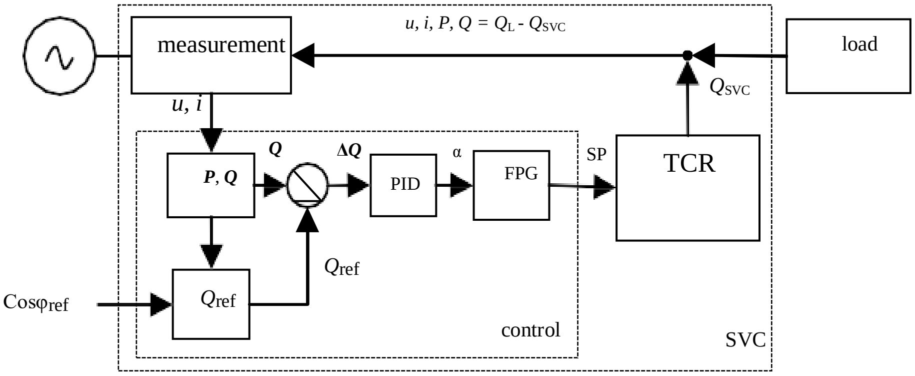

Fig. 6 PID controller for SVC

c) Real-time PID Algorithm for SVC

In this system, the active power (P), the reactive power (Q), and the power factor (Cosφ) are determined by the selec MFM384. The S7-200 PLC communication between the Modbus and the selec MFM384 is applied to receive the measured parameters and then calculate the reactive reference power based on the reference Cosφref. The control signals automatically derived by the PID controller are sent to the thyristor reactive power regulator. As a result, the value of the measured power factor (cosϕ_mea) satisfies the reference and keeps fixed. The real-time system is depicted in Fig.7.

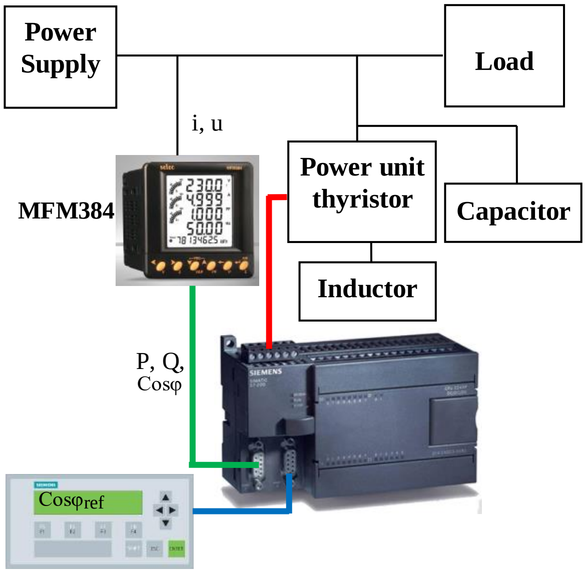

Fig. 7 Structure of SVC real-time control

Fig. 8 Real-time PID controller of PLC for SVC

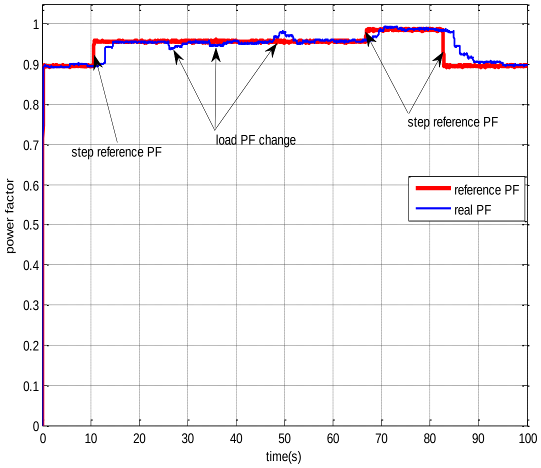

Fig. 9 The result of the Real-time PID controller for SVC

III. CONCLUSION

The experiment results in real-time contribute a correct reactive power compensation system. The measured value of the power factor cos-phi meets the demanded value and is remained stable. Stepless adjustment enables better compensation according to load power factor variations. By using the available PID controller in S7-200 PLC, the system performance becomes more reliable and easier to synchronize with automation solutions applied in the power grids.

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