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(54) **Title:** A METHOD FOR OPERATION OF A SHUNT ACTIVE COMPENSATOR

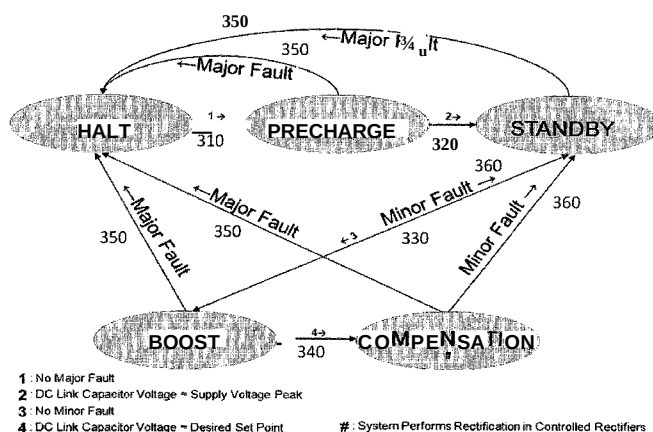


Figure 3

(57) **Abstract:** A method for seamless interface between various software modules in a dynamic reactive power compensator is provided in the invention. The method is illustrated for a shunt active compensator connected parallel to a single phase or multi-phase electric line. The shunt active compensator comprises a pre-charge contactor, a main contactor, a power converter, one or more components such as reactors, one or more resistors and one or more DC capacitors connected to the power converter. The method of operation of the shunt active compensator comprises having identified states such as a halt state, a pre-charge state, a standby state, a boost state and a compensate state in the shunt active compensator, operating the shunt active compensator in one of the identified states and having a state transition in the operation of the shunt active compensator based on a determined condition in the shunt active compensator. The state transition during normal and fault operations are illustrated along with the determining factors for the state transition in the shunt active compensator.



A METHOD FOR OPERATION OF A SHUNT ACTIVE COMPENSATOR

Field of Invention

The invention relates to a dynamic reactive power compensator at low-tension side and more specifically to a method for seamless interface between various software modules in the dynamic reactive power compensator for reliable operation of the dynamic reactive power compensator.

Background of the invention

Power compensators are required for industrial and other loads. These compensators offer dynamic response and continuously compensate the varying load reactive power and allow unity power factor operations at the input supply within its capacity. A shunt active compensators/rectifiers are class of grid connected power electronics based equipment used for power quality applications or controlled rectification of power respectively. They use fully controlled semiconductor devices like IGBTs, MOSFETs, IGCTs etc. as switches. They are available in single phase and poly phase topologies. Compensators may perform reactive power compensation, harmonic filtration and/or load balancing. The shunt active compensator/rectifier is being referred as a "System" in this invention.

The operation of shunt active compensator and active rectifier systems are usually complicated. A robust protocol is needed for the sequencing of system components, which supplements the control algorithm and ensures higher reliability and flexibility of operation. The invention describes a method for achieving this.

Summary of the invention

In one aspect of the invention a method for operation of a shunt active compensator connected in parallel to a single phase or multi-phase electric line is provided. The shunt active compensator comprises a pre-charge contactor, a main contractor, a power converter, one or more reactors, one or more resistors and one or more DC capacitors connected to the power converter. The method of operation of the shunt active compensator comprises the steps of:

- a) Having a number of identified states of shunt active compensator; the identified states be a halt state, a pre-charge state, a standby state, a boost state and a compensate state.
- b) Operating the shunt active compensator in one of the identified states; and

- c) Having a state transition in the operation of the shunt active compensator based on a determined condition in the shunt active compensator.

In an embodiment, the method further comprises of a step of transition from the halt state to the pre-charge state or from the standby state to the boost state is effected on detection of no fault condition.

In another embodiment, the method further comprises a step of operating the shunt active compensator in the pre-charge state carried out by having the pre-charge contactor switched ON to connect and charge the components of the shunt active compensator in a controlled manner.

In another embodiment, the method comprise a step of transition from the pre-charge state to the standby state is effected on detection of a condition determining completion of the pre-charge activity in the shunt active compensator.

In another embodiment, the method for operation of the shunt active compensator in the standby state is carried out by having the main contactor switched ON to connect the power converter to the electric line through the series reactor.

In another embodiment, the method has a step of transition from the standby state to the boost state carried out by operating the power converter to boost the voltage at the DC capacitor to a preset set point.

In yet another embodiment, the method has a step of transition from the boost state to compensation state carried out on detection of the voltage at the DC capacitor connected to the power converter reach a preset set point value.

In yet another embodiment, the method has a step of transition from the boost state or the compensation state to the standby state carried out on detection of any minor fault in the shunt active compensator.

In yet another embodiment, the method has a step of transition to the Halt state from any other state is carried out on detection of any major fault in the shunt active compensator.

Brief Description of the Drawings

These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

Figure 1 provides an exemplary single phase topology for a shunt active compensator;

Figure 2 provides an exemplary three phase topology for a shunt active compensator;

Figure 3 provides exemplary state transitions during operation of a shunt active compensator;

Detailed Description

A typical single phase topology for a shunt compensator is illustrated in Figure 1. An exemplary shunt compensator 100 connected in parallel to the line 110. The operation of System typically follows the following sequence

1. The main contactor, 120, pre-charge contactor, 130, and power semiconductor switches in the single phase converter, 140 are initially in off state.
2. The pre-charge Contactor 130 is turned on. Capacitor C charges to the supply Voltage peak through the pre-charge resistor R. The power converter is connected to the source through pre-charge resistor R and inductor L. This process ensures that the system is switched on without any in-rush current transients.
3. The main contactor 120 is switched on followed by the turning off of pre-charge contactor. The power converter in connected to the source through inductor L.
4. The power converter 140 is modulated to boost the voltage of Capacitor C, connected to the power converter 140, to a suitable magnitude, which is above the peak of supply voltage. The power switches Q1-Qn in the converter are pulse width modulated during this stage.
5. After the capacitor C has reached a desired magnitude, the power converter starts compensating or performs active rectification.

Figure 2 depicts an illustrates an exemplary topology with three phase converter 210 for the compensator. The operation of this remains the same as that of the single phase compensator described above.

During faulty conditions, depending on the severity of fault either only the power semiconductor switches in the converter 140 or power semiconductor switches in the converter 140 along with main contactor 120 is needed to be turned off. The system has to follow a complex sequence to recover from the fault. The objective of this invention is to simplify the sequencing operation during boot-up, fault conditions and fault recovery. This is being carried out by having a state machine approach defined for simplify the sequencing described earlier. It also has the added benefit for the system as the system would then operate in a flexible, fast and robust manner.

The system may be operated in the step of precharge, standby, boost and compensate and to have states defined for operation in a fault state. For instance, in case of a minor fault, the system goes to standby and in the instance of major fault, the system goes to a halt state.

The system may be defined to have the following states.

- HALT State (1)
 - Converter is isolated from the grid. Power Semiconductor Switches are off.
- PRECHARGE State (2)
 - Converter is connected to grid through the Pre-Charge Resistor and series reactor
- STANDBY State (3)
 - Converter is directly connected to the grid through the series reactor
- BOOST State (4)
 - Power Semiconductor Switches become operational with DC Capacitor Bus Boost Command
- COMPENSATION State (5)
 - Converter is operational with suitable current reference

The state table **Table 1** shows the status of different components in system during different states. The state diagram **Figure 3** shows the system transitions.

	PRECHARGE Contactor	MAIN Contactor	Converter Status	I_{system} Reference
HALT (1)	0	0	0	0
PRECHARGE (2)	1	0	0	0
STANDBY (3)	0	1	0	0
BOOST (4)	0	1	1	0
COMPENSATION (5) #	0	1	1	I _{Demand}

Table 1. State Table for operation of a shunt active compensator

The system remains in the halt state as long as any major fault condition exists. As the major fault condition gets cleared, the system transits (310) to the pre-charge state and the pre-charge contactor (130) is turned on. DC Link starts charging through the resistor R. When the DC link voltage reaches the peak of supply voltage, system transits (320) to the standby state. In standby state, pre-charge contactor (130) is disabled and main contactor (120) is enabled. System remains in the standby state if any minor fault condition exists. The System transits (330) to boost State, if minor fault conditions are cleared or not present.

In boost State power semiconductor switches are turned on. The Converter is modulated with DC boost command. When the DC link reaches the boost set point, system transits (340) to compensation/rectification state (also referred as compensation state). In compensation state, power converter is ready for operation. It is operated with desired current reference as suitable to provide compensation.

During minor fault conditions (eg internal fault such as misfiring of the semiconductors in the compensator, input supply over/under voltage, DC over voltage, input supply unstable,

frequency varying very fast etc.), as determined by the system, the system transits (360) to the standby state. In the standby state, power semiconductor switches are turned off. When the fault condition clears, system transits to boost state and further to compensation states.

During major fault conditions (eg a short circuit condition in the line 110, power switch short circuit, over temperature condition, power converter failure, cooling system failure, user interruption etc), as determined by the system, the system transits (350) to halt state. In the halt state, power semiconductor switches and main contactor are turned off. When fault condition clears, system transits through pre-charge, standby, boost states and finally to the compensation state.

The state machine seamlessly interfaces with other software modules like Fault Manger, Energy Optimizer, Power Controller etc that make use of one or more states of operation of the shunt active compensator and makes the system to function in a versatile manner. The system robustly manages itself during faulty network conditions, faults in the system and during normal power-up conditions. The intelligence offered by this state machine, reduces the need of human intervention for maintenance of the system.

The state machine is implemented in a software form, embedded in the system and offers versatility and increased value for the product.

While only certain features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

1. A method for operation of a shunt active compensator connected in parallel to an electric line and comprising a pre-charge contactor, a main contactor, a power converter, one or more components such as reactors, resistors and DC capacitors connected to the power converter, the method comprising the steps of:
 - a) Having a number of identified states of shunt active compensator; wherein the said identified states of the shunt active compensator are from the group of states consisting of halt state, pre-charge state, standby state, boost state and compensate state;
 - b) Operating the shunt active compensator in one of the identified states; and
 - c) Having a state transition in the operation of the shunt active compensator based on a determined condition in the shunt active compensator.
2. The method as claimed in Claim 1 wherein the step of transition from the halt state to the pre-charge state or from the standby state to the boost state is carried out on detection of no fault condition.
3. The method as claimed in Claim 1 wherein the operation of the shunt active compensator in the pre-charge state is carried out by having the pre-charge contactor switched ON to connect and charge the components of the shunt active compensator in a controlled manner.
4. The method as claimed in Claim 1, wherein the step of transition from the pre-charge state to the standby state is carried out on detection of a condition determining completion of the pre-charge activity in the shunt active compensator.
5. The method as claimed in Claim 1 wherein the operation of the shunt active compensator in the standby state is carried out by having the main contactor switched ON to connect the power converter to the electric line through the series reactor.

6. The method as claimed in Claim 1 wherein the step of transition from the standby state to the boost state is carried out by operating the power converter to boost the voltage at the DC capacitor to a preset set point.
7. The method as claimed in Claim 1 wherein the step of transition from the boost state to compensation state is carried out on detection of the voltage at the DC capacitor connected to the power converter reach a preset set point value.
8. The method as claimed in Claim 1 wherein the step of transition from the boost state or the compensation state to the standby state is carried out on detection of any minor fault in the shunt active compensator.
9. The method as claimed in Claim 1 wherein the step of transition to the Halt state from any other state is carried out on detection of any major fault in the shunt active compensator.
10. A shunt active compensator for power compensation in a single phase or a multi-phase electric line operated in accordance with any of the preceding claims.

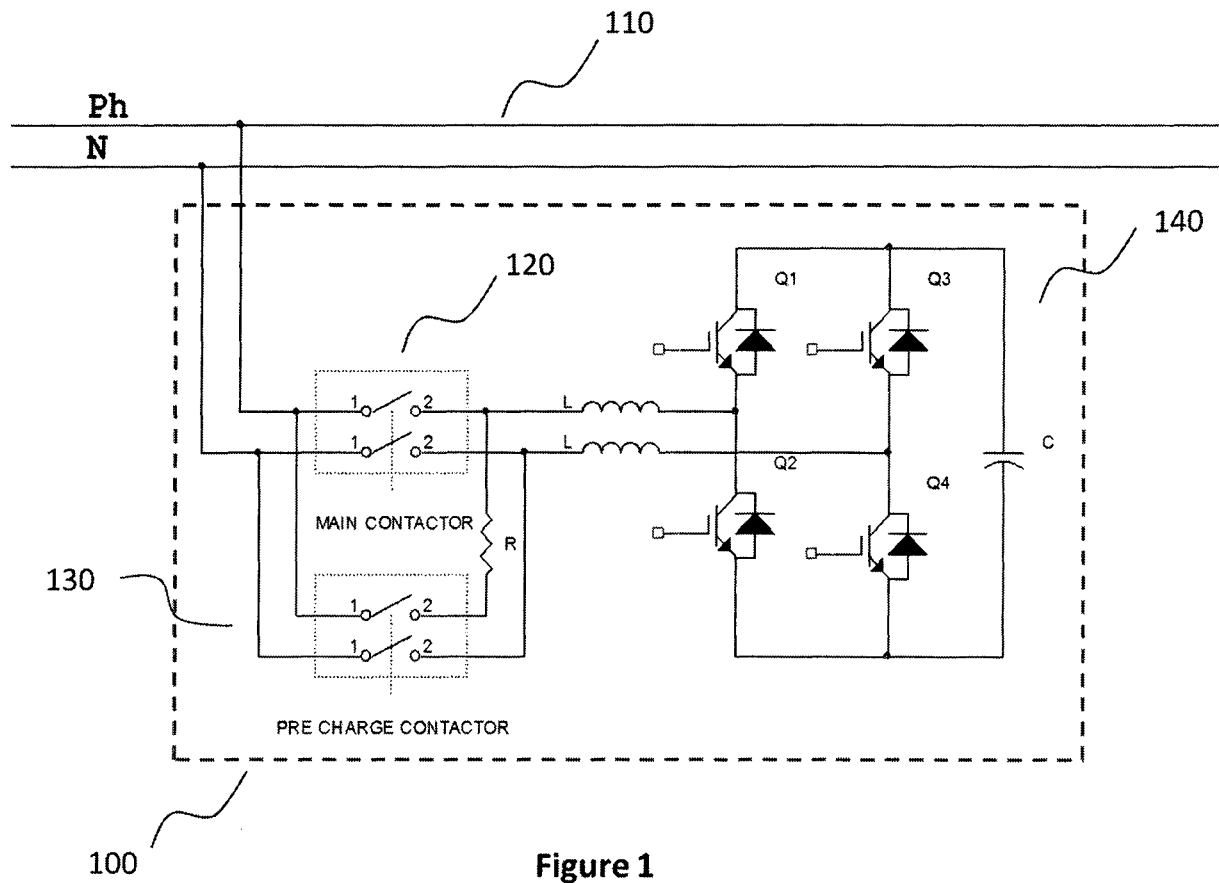


Figure 1

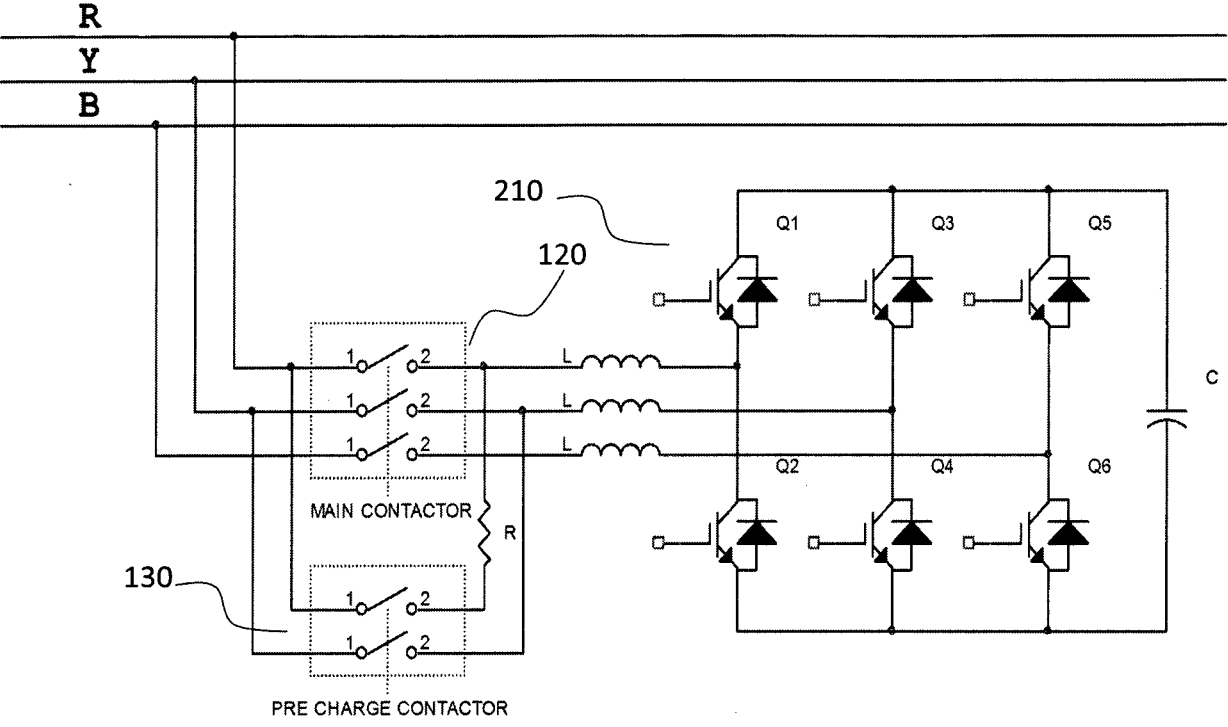


Figure 2

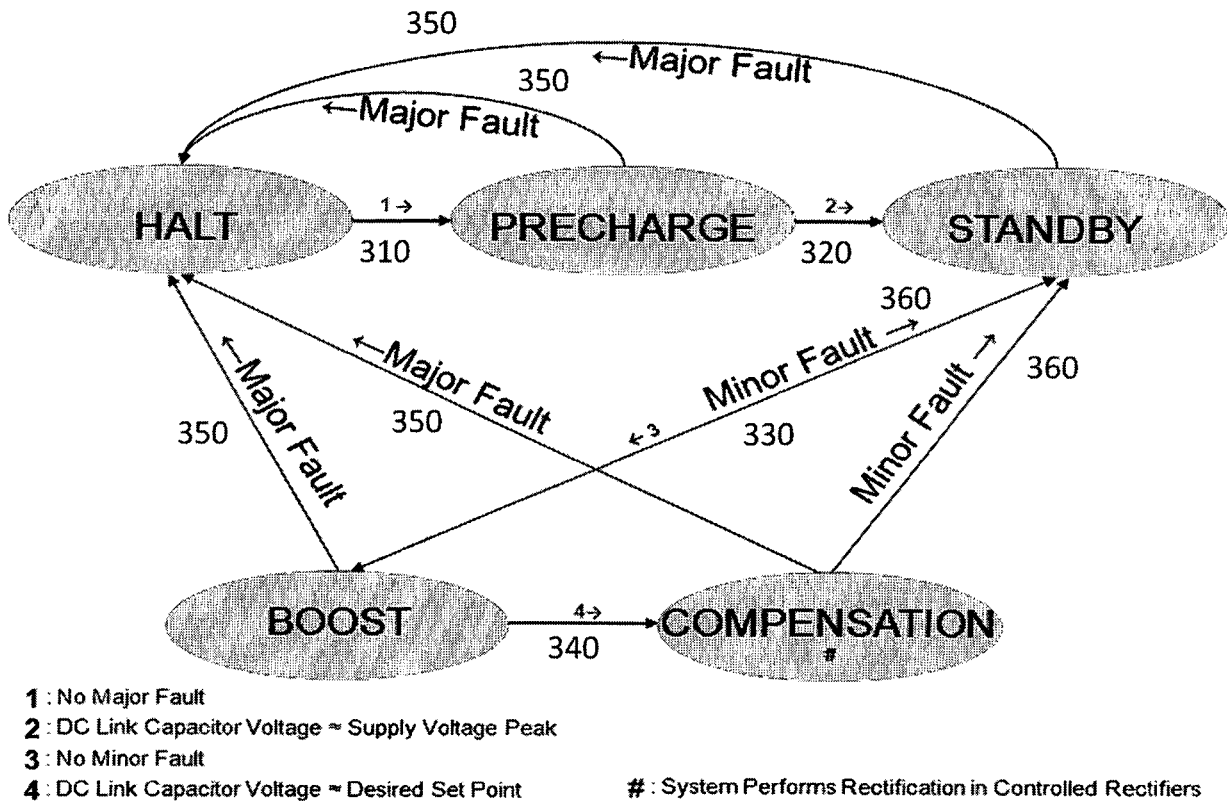


Figure 3