Industrial^{IT} Power Management System

Functional Overview

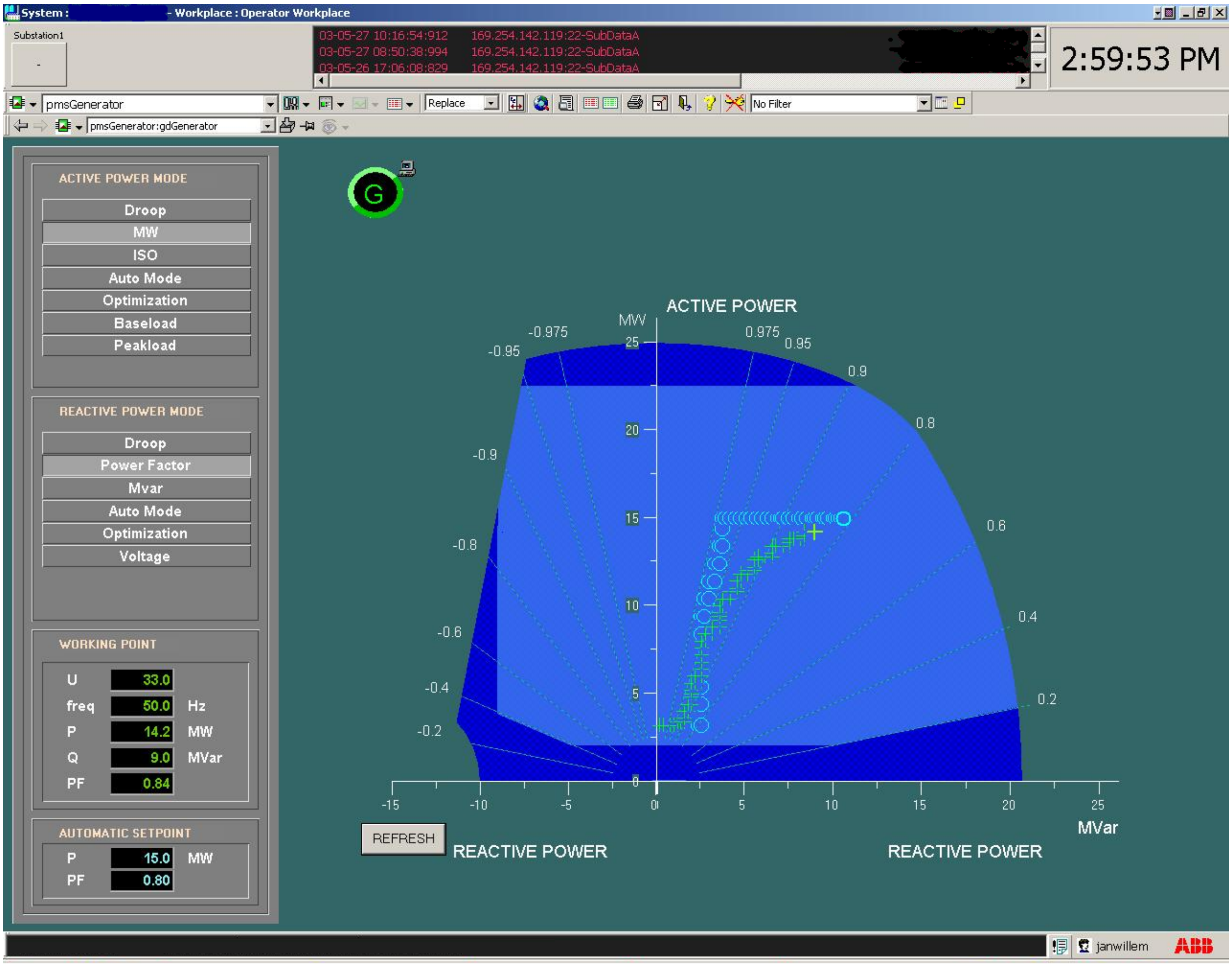

TABLE OF CONTENTS

1. INDUSTRIAL^{IT} POWER MANAGEMENT SYSTEM

1.1. Introduction

This document provides a brief description of the functions of ABB's Industrial^{IT} Power Management System. ABB's Industrial^{IT} Power Management System is a software solution targeted at ensuring

- the availability of energy

and

- its efficient, economic and sustainable use

The Industrial^{IT} Power Management System (PMS) provides functions for the control and supervision of the power-generation and -supply in industrial plants. The main reason for implementing a PMS is very often the need for Load Shedding. This advanced functionality drastically increases the overall plant safety by assuring electrical power and steam for critical loads and by preventing blackouts. The costs, caused by production losses, of a complete blackout can easily amount to up to one million $ per blackout. The PMS offers the functions to ensure safe operations with less personnel. Better, faster and more comprehensive information from the process is therefore a necessity.

Furthermore, in sectors such as the oil & gas and petro-chemical industries, energy costs represent at least 30-50 % of the production costs. The PMS enables you to increase the efficiency of energy use, thus significantly reducing energy costs. Therefore the pay back time of PMS is very short (<less than 2 years as reported by all our customers).

The PMS also allows for more critical designs of the electrical equipment in a plant. The system will re-arrange energy generation, import and loading in such a way that the individual generators, reactors, transformers, and tie-lines are operated well within their specifications. The integration and serial communication with Motor Control Centres, Protection Units, Governor controllers, Variable Speed Drives and other subsystems yield high savings in copper wiring and maintenance costs. The optical connections provide a rigid network that does not suffer from electromagnetic interference.

Since 1986 ABB BV in Rotterdam, the Netherlands has been actively working in the field of Industrial Electrical Power Management Systems (PMS). Throughout a large number of projects realized across the world, the power automation group based in Rotterdam, has built up specific application know-how regarding the control and monitoring of electrical networks for industrial process plants. This is reflected in the extensive and standardized PMS functionality that has gained wide acceptance among its users.

Within ABB worldwide, ABB in the Netherlands has officially been recognized since 1996 as the Center of Excellence (COE) for Power Management Systems for the oil & gas, petroleum and chemical industries.

In the last quarter of 2002, the COE has also been made responsible for the broadening of ABB's solution offering in this area with functionality for energy optimization and environmental management.

A wide range of products is available for a cost-efficient and reliable engineering and implementation of the PMS. The well-tested and -documented products (software type circuits and system software modules) guarantee a significantly decreased project execution time and (even more importantly) shorter commissioning periods.

PMS projects can be executed by local ABB companies, with the support of the COE in the form of project execution assistance either and by providing tools such as project quality control plans, frames for functional design specifications and pre-defined project time schedules. These tools contribute to a smooth and optimised project execution.

For further information about the Industrial[IT] Power Management System, please contact:

ABB B.V.
Marten Meesweg 5
NL-3068 AV Rotterdam
The Netherlands

Otto van der Wal / Pedro Fernandez-Gomez
Tel.: +31 10 4078 911
Fax: +31 10 4078 452
E-mail: otto.wal@nl.abb.com

S.A. ABB N.V.
Hoge Wei 27
BE-1930 Zaventem
Belgium

Guy Frederickx / Luc Van de Perre
Tel.: +32 2 718 65 19
Fax: +32 2 718 64 99
E-mail: guy.frederickx@be.abb.com

1.2. PMS Main Functions

On the following pages we will provide an overview of the main functional blocks that make up the PMS. These functions are:

- Network Configuration Determination
- Load Shedding
- Re-acceleration
- Power Control
- Generator Control
- Synchronisation
- Breaker Control
- Motor Control
- Tap Changer Control

2. NETWORK CONFIGURATION DETERMINATION

The “Network Configuration Determination” function analyses the electrical network configuration determined by the status of the tie-line breakers, bus couplers and generator breakers.

This function is very important as many other functions rely on it, such as auto sequencing, load shedding, re-acceleration, active power control, reactive power control, transformer control and generator control.

The electrical network has a number of breakers of which the status determines the actual network configuration(s). When the status of the breakers (connect/disconnect bus bars) are read, the function generates the actual network configuration. The result is written in a register. The output of the register is used by the other functions. In the electrical network, many possible network configurations can be determined. A network configuration is defined by the checked and approved, opened or closed position of the breakers involved. The status of these breakers is the basis for the network determination.

Each breaker can have two positions, either opened or closed. If one of these breakers has an intermediate position, then this is a non-existing configuration and an audible alarm is generated. Because of the unreliability of this situation, a network configuration change itself will not take effect. An electrical island is only of interest if it consists of at least one machine. If, for example, a maximum of 6 machines are in operation, no more than 6 islands can be formed simultaneously.

3. LOAD SHEDDING

3.1. General

The load shedding system has to ensure the availability of electrical power to all essential and most critical loads in the plant. This is achieved by switching off non-essential loads in case of a shortage of power in the plant electrical network, or parts of the plant electrical network. A shortage of electrical power can be caused by loss of generation capacity or disconnection from the public power company supply.

The load shedding system can be invoked by one or more of the following functions:

- primary load shedding
- frequency load shedding
- manual load shedding
- maximum peak power demand shedding

The main input for the load shedding system is the register received from the “Network Configuration Determination” function, which determines the configuration of the electrical network. The configuration is determined on the basis of the checked breaker positions.

In the second place, load shedding needs data from the load flow in the network. Data (which has been validated by the software) regarding the loads on the busses and the power generated by each generator is sent to the central load shedding function by analogue inputs. Where available, the measured power of each load is used. This data can be received from the analogue inputs in the process controllers or via serial links to the MCC’s. When there is no power measurement available for a particular load, the corresponding position of the breaker is used together with the nominal power value. Load shedding uses data representing the load flow in the network, which is at least 2 seconds old, to prevent load shedding based on data which was obtained while the network was already in a faulty, and therefore, unstable condition.

Finally, load shedding also requires operator input. For the load shedding functionality maximum 20 priorities are used. For each load all priorities can be defined by the operator. Priority 20 is reserved for all non-sheddable loads or loads which are disabled for load shedding. Within each priority also 10 groups can be defined. A group is the smallest sheddable unit. For each load for which the load shedding option is active, the operator at the central point of control can change the priority and enable/disable the load shedding function.

The elapsed time between opening a circuit, reading a digital input in any of the Advant Controllers and issuing the load shed command, at a particular output in any of the Advant Controllers, is maximum 150 milliseconds. For crisis signals, the transducer reading is not used when determining whether a breaker is open. This is because the transducer needs approximately 300 milliseconds to settle, which would make the load shedding action too slow. Preferably, if possible, a 2 out of 3 reading has to be used for the circuit breaker positions, which are used as crisis signals.

3.2. Primary Load Shedding

The following main functions are part of the primary load shedding system:

- continuously checking for changes in the total electrical network configuration
- continuously checking the energy balance in every electrical island configuration
- calculation of the dynamic priority load tables
- generation of the load shed command when needed
- supervision of the total PMS computer system
- generation of reports after load shedding
- informing and guiding of the operators

The load shedding system continuously checks whether changes in the island configuration occur. As soon as a change occurs, e.g. the tripping of a generator, the load shedding system starts checking all the individual island configurations. For every island configuration, the energy balance has to be calculated. If the load in an island configuration exceeds the available generated power, it is necessary to shed the surplus of loads.

For every island configuration, which is momentarily in a steady state condition, the load shedding system has to continuously monitor the power available from the generators in that particular island configuration. This is due to the fact that losing a generator or losing a part of the capacity of a generator may cause the need for load shedding.
As soon as load shedding is initiated, due to a change in the electrical network configuration (*which does not meaning that a real shed command will be generated*) the system starts calculating the dynamic priority load shed tables. Input for this calculation is the data in the island configuration and the priority load tables for the several busses. For every bus with sheddable loads, such a priority load table is assembled.

The priority load table for every bus is assembled in order of priority. Calculation of the priority load table is done in the background. From this priority load table an accumulated priority load table per bus is obtained. As soon as load shedding is started, an accumulated priority load table for the whole island configuration is calculated. If the result of the energy balance calculation leads to the conclusion that load shedding is needed, the quantity of power to be shed is also obtained from this energy balance calculation. This quantity is then compared with the contents of the accumulated priority load table for the island configuration. The load shed command is generated and sent to the unit where the loads are actually connected. The primary load shedding functionality is implemented in two parts:

- central part
- substation part

The central part of primary load shedding functionality is implemented in the central node. The substation part of primary load shedding functionality is implemented in the one or more substation nodes. For small load shedding applications, the central- and the substation part of the primary load shedding can both be implemented in the central node.

3.3. Frequency Load Shedding

This function is more or less the backup for the primary load shedding function, which is described above. When the primary load shedding fails due to wrong inputs, this function will shed the loads. Frequency load shedding not only takes the absolute frequency limits into account, but also calculates the df/dt. This allows for a more accurate load shedding. The frequency limits are read in from frequency relays by digital inputs in the Advant Controller.

3.4. Manual Load Shedding

Also the operator can issue a plant-wide shed priority. To assist the operator in assessing how much load will be shed if he issues a manual load shedding priority, the main load shedding process display shows an accumulated priority load table for the total actual plant load per priority.

3.5. Maximum Peak Power Demand Shedding

Some priorities can be shed as soon as the power taken from the public grid tends to exceed the maximum allowed quantity when in-house generation is maximised. This import maximum is based on periodical power demand. In this case, the operator can deactivate the mechanism, and also determine up and until which priority automatic load shedding can be carried out by this function. Certain priorities can be excluded from maximum peak power shed. Before the shed command, an audible alarm is generated, so that an action can be taken, if there is time, to overcome the situation.

4. RE-ACCELERATION

In case of faulty situations, such as bus under-voltage or load shedding, the loads are disconnected from the bus. The purpose of the re-acceleration function is to determine which loads can be reconnected as soon as the network or parts of the network have recovered from the under-voltage situation. After a load shedding action, however, the operator has to release the re-acceleration function manually by means of a general reset.

Re-acceleration is executed according to priorities and maximum disconnected times, defined in tables. The system determines which loads can be re-accelerated taking into account:
- available island power
- priorities
- restart time
- network stability timer

Any load shedding action, either primary, thermal load shedding or manual shedding, halts the execution of re-acceleration.

To execute the re-acceleration function as efficiently as possible, the distribution of available power is executed in several 'power assignment' steps, thus making re-acceleration an iterative process.

While the start-up load of most electric loads is much larger than the load in normal operation, it is possible that with the power that is assigned to the substation, only a few loads can be re-accelerated. After these few loads have been started up, the power consumption decreases to a fraction of the available power.
There will still be power available to start-up other loads. All substation nodes again access the amount of power that can be re-accelerated.

If from all substations the 'ready' signals are received, a next power distribution calculation is executed. Re-acceleration stops if all delay timers of the loads have expired, as indicated in the substation nodes. If re-acceleration load from the substations equals zero and all ready bits are received, re-acceleration is finished.
If loads have been shut-off by load shedding, re-acceleration starts if a reset load shedding signal has been issued by the operator.

5. POWER CONTROL

5.1. Active Power Control

"Active Power Control" consists of the following system-wide functions:

- **MW demand control**

  To ensure that the amount of imported power is kept at the desired setpoint, if possible in-line with the available in-plant generation. The function also has to take care that contracted peak demand, in most cases measured as a sliding 15 minutes demand, is not exceeded.

- **Bus frequency control**

  The bus frequency control function is responsible for maintaining / re-establishing the bus frequency at the desired frequency for a certain bus bar or a combination of bus bars - in case the bus bar or island is disconnected from the public grid. The latter especially applies if the electrical load of the bus bar is changing.

  For every island only one machine can be the "master of frequency". Frequency control can be performed by a separate controller which is enabled by the bus frequency function and receives its setpoint from this module. It can, however, also be done directly by the generator control type circuit in the PMS and the machine running in droop mode. In the latter case the frequency is maintained sending "raise/lower" pulses to the governor.

  Enabling frequency control for a machine is interlocked as long as the machine is connected to the public grid or to another machine which is the "master of frequency". As soon as the frequency exceeds a high or a low limit an audible alarm is created.

- **MW sharing control**

  If two or more machines are operating in parallel in the same electrical network and this network is not connected to the public grid, one of the machines very often is operating in frequency or isochronous mode. The result of this is that the machine in frequency mode takes all the load changes in this particular island, while the other machines, which might run in MW mode, keep operating on the same working point. This could result in a situation where one machine is running very close to the limits of its capability curve while the other machines are running quite comfortably within the limits of their capability curve. This should be avoided.

  The MW sharing function re-calculates the working point of the machines that are connected in the electrical network and for which MW sharing control is enabled. The re-calculation is done by comparing the actual working point to the borders of the capability curve (control margin).
  In these controls at least one machine is participating, but usually more than one machine is involved. For each machine an individual generator control type circuit is implemented, as described below in the paragraphs on Generator Control.

  The active power control sends setpoints to each generator control module which is enabled to take part in that particular control action.
  Whether it is possible to enable one of the above control modes, depends on the electrical network configuration which is determined by the "Network Configuration Determination" function.

5.2. Re-active Power Control

The PMS has facilities to control the setpoint assigned to the controllers (AVRs) of the power generation units. The setpoints are given only if the system or the operator sets the AVRs' control module of the involved power generation units in PF control mode.

The "Reactive Power Control" function optimises the amount of reactive power exchanged with the Public Power Company or follows a setpoint for the power factor. It does so by optimising the reactive power generated by the power generation unit. The reactive power to be generated by these units is spread across the units based on their capacity to take more reactive load. In case the electrical plant network is in island operation the reactive power control function controls the voltage and gives the setpoint to the AVR.

The reactive power control function has the ability to calculate the capability curve of the units. From this capability curve the module determines how to divide the reactive power. This function covers the system wide functions:

- **PF demand control or MVAr control**

  The PF demand control function offers the possibility to maintain an adjustable power factor setpoint at the exchange point with the public grid. The setpoint is usually determined by the contracted minimum power factor.
  Depending on the contract with the public power company the algorithm is tuned. Often the decisive moment for the power factor is related to the maximum peak power demand in active power. Apart from the criteria given by the contract the operator has the opportunity to specify a setpoint in the system. This allows to operate on the safe side.

- **Voltage control**

  The voltage control function has the objective to maintain the bus voltage at a desired level, even after major load changes. In any electrical island only one generator can be set to control the voltage. Which generator is controlling the voltage in an electrical island is determined by the "Network Configuration Determination" function in conjunction with a pre-prepared table.
  In electrical islands that are connected to the public grid the transformer voltage control takes care of the bus voltages.

- **MVAr sharing control**

  If two or more machines are operating in parallel in the same electrical network, and this network is not connected to the public grid, one of the machines very often operates in voltage mode. The result of this is that the machine in voltage mode takes all the reactive load changes in this particular island, while the other machines which might run in MVAr control mode keep operating on the same working point. This could result in a situation where one machine is running very close to the limits of its capability curve while the other machines are running quite comfortably within the limits of their capability curve. This should be avoided.
  The MVAr sharing control function re-calculates the working point of the machines connected in the concerned electrical network and for which the MVAr sharing control mode is enabled. The re-calculation is again done by comparing the actual working point to the borders of the capability curve (control margin).
  MVAr sharing control mode can only be enabled for the machines that are isolated from the grid. Audible alarms are generated as soon as machines in MVAr sharing control mode are operated too close to their respective capability curve.

In these controls at least one machine is participating, but usually more than one machine is involved. For each machine an individual generator control type circuit is implemented, as described below in "Generator Control".
The reactive power control module sends setpoints to each generator control that is taking part in that particular control action. Whether it is possible to enable one of the above control modes, depends on the electrical network configuration which is determined by the "Network Configuration Determination".

5.3. Auto Sequencer

As the governor- and AVR control mode of a machine are subject to the network configuration to which the machine belongs, network configuration changes may require a change of the actual control modes. After a network configuration change, the “Auto Sequencer” function sends, a message to all participating objects with the desired operating mode. These operating modes are stored in the table "Default Island Mode Settings" (DIMS). This table can be defined by the operator and only has a meaning for island configurations.

In order to be able to perform this task, the “Auto Sequencer” function continuously receives the actual electrical network configuration from the “Network Configuration Determination” function. The operator is always allowed to change the actual mode of an individual machine.

If the “Auto Sequencer” function changes a control mode of the governor or the AVR of one of the machines, an audible alarm is generated.

5.4. Default Island Mode Settings

To allow for easy mode changes, there are no interlocks between modes or mode changes in the DIMS table. However, for each island configuration an indication is created to warn the operator in case a setting in the DIMS results in an erroneous operation mode of the machines. The conditions for messages are restricted for the status of objects in one power station only.

There are no interlocks between the DIMS table set-up and the actual control mode of the machine dialogue. After the set-up in the DIMS table has changed, the operator has to verify that no warning exists. As long as a warning for a configuration exists, the set-up for that configuration is not valid.
If the operator ignores the warning, the “Auto Sequencer” function will change the governor and/or AVR to the droop control mode if the warning is active at the very moment that the configuration is detected.
A change according to the DIMS table set-up can be made at once for all machines of one powerhouse from a special DIMS table dialogue, or manually by selecting the individual machine concerned.

6. GENERATOR CONTROL

For each machine in the electrical network, the “Generator Control” function is used. The “Generator Control” function is able to operate machines in different electrical network configurations, in island and in parallel. The “Generator Control” function is also able to co-operate with the “Active Power Control” and “Reactive Power Control” functions.

For each machine a control mode can be selected for both governor and automatic voltage regulation (AVR) individually. The behaviour of the machine is subject to this control mode and to changes or fluctuations detected in the electrical network or steam system. Some control modes can be selected only in dedicated network configurations.

In the single line diagram displays of the electrical network, the generators are only presented by the most important actual measured analogue data. Dedicated displays are available for more detailed generator information, e.g.:

- **Generator Overview**

  Detailed generator data is presented in a table regarding the actual control mode of the governor and the AVR, working setpoint and some alarms.

- **Capability Diagram**

  The capability diagram of the generator includes dynamic working point tracking, actual control mode, setpoint, working point and all related analogue data.

7. SYNCHRONISATION

The synchronisation function implemented in the “Generator Control” function is invoked by the selection of the generator breaker from the central point of control. When synchronisation is required, the generator name to use for the synchronisation can be entered by the operator, where after the generator dialogue automatically will be presented and will be set into droop control mode. By selection of the synchronisation command from the generator dialogue, the synchronisation can be continued into manual or automatic mode.

The PMS offers the operators the capability to synchronise automatically. The selection of the circuit breaker and the corresponding generator is done from the ABB Operator Station. The software module determines which voltages should be applied to the synchroniser and relays are activated by the control system in such a way that these voltages are actually applied to the synchroniser. The synchroniser will send the “raise/lower” pulses to the appropriate governor and the exciter by means of a relay circuit that is controlled by the control system. At the moment synchronism is achieved the synchroniser will release the close command. It is clear that a synchrocheck relay has to be available for each circuit breaker that has to be synchronised.

The synchronisation module also allows for manual and semi-automatic synchronisation. In manual mode the operator has to issue the “raise/lower” commands from the keyboard and as soon as synchronism is reached give the close command. It is obvious that the close command has to be released by a synchrocheck function. This synchrocheck function can be available locally at the circuit breaker or can be included in the synchroniser which is located in the central system.
In semi-automatic mode the “raise/lower” commands are invoked by the synchroniser but the actual closing command is still given by the operator. Again this command has to be validated by a synchrocheck functionality.

8. BREAKER CONTROL

Breaker control can be used for one or more points of control (remote, central and/or local). Breaker control consists of a basic set of functions (status conditioning and supervision, command supervision, support of different position limit switches) and a number of (optional) additional functions.

Breaker control can be used for a single (synchronising) breaker or disconnector and for control of two incoming feeders and one bus coupler breaker in a panel configuration.

For the panel configuration, two automatic functions are optional:

- **Load Transfer**

  The load transfer function secures the electrical power supply for the loads connected to a bus bar or part of a bus bar, which is not fed any more because the incoming feeder or the bus coupler breaker has been tripped by under-voltage.
  When the central mode becomes active, the control mode value from the remote panel will be taken over. After this the operator can control the auto/manual control mode from the incoming feeders or bus coupler breaker dialogue.
  The load transfer will be performed only in central mode by closing an incoming feeder or bus coupler breaker as soon as transfer conditions are met.

- **Opening Breaker**

  The opening breaker function opens one of the two incoming feeders downstream or the bus coupler breaker after a tuneable time-out, thus avoiding parallelism for a longer time. Beforehand the operator chooses which of the two incoming feeders or bus coupler breaker has to be opened (default setting is the bus coupler breaker). The opening breaker function is only active in central mode when the two following conditions are met:
  - *the two incoming feeders and bus coupler breaker are closed during a tuneable time-out*
  - *none of the two incoming feeders or bus coupler breaker is in the racked-out position*

9. MOTOR CONTROL

The motor control function can be used for one or more points of control (remote, central and/or local). Motor control consists of a basic set of functions (status conditioning and supervision, command supervision) and a number of (optional) additional functions, such as:

- automatic start mode
- forward/backward control
- load shedding
- re-acceleration
- running hours calculation

For each motor with the load shedding option, the operator at the central point of control can:

- change priority (from 1..20)
- change group (smallest sheddable unit within a priority)
- enable or disable load shedding functionality

For each motor with the re-acceleration option, the operator at the central point of control can:

- maximise the shut-off time
- change the re-acceleration priority (from 1..20)
- prohibit or enable re-acceleration functionality

10. TRANSFORMER CONTROL

The transformer control can be used for one or more points of control (remote, central and/or local). The transformer control consists of a basic set of functions (status conditioning and supervision, command supervision) and an (optional) additional functions:

- count number of tap changer operations

The purpose of the function “On-Load Tap Changer Control (OLTC)” is to maintain a constant voltage at the low voltage side of the EHV power transformers. In some rare cases the voltage at the high voltage side has to be regulated. The module allows for this as well. The transformer control consists of two function blocks, one for single control of tap changers and one for the parallel operation of transformers. Main features of the transformer control module are:

- checking and changing of important parameters from the ABB Operator Station
- blocking of controls if voltage or current limitations are violated (blocking on conditions of circuit breakers, disconnectors, communication and tap changer position)
- line drop compensation
- constant or inverse relationship between the voltage deviation from the setpoint and the time delay before operating the tap changer

10.1. Operating Principles

The basic input for the tapchanger control function is the phase-to-phase voltage on the low voltage side of the transformer and the three phase currents at the low voltage side.
The measured voltage (UB = UL1 - UL3) is used for the voltage control and the protection of the tap changer whereas the phase currents IL1, IL2 and IL3 are used for protection of the tap changer only. The setpoint voltage is denoted as US and the tap changer will start working as soon as the difference between US and UB is too large. A voltage/time characteristic is included in the basic tap changer control function to determine the delay time before starting the tap changer. The tap changer operation is disabled under conditions which would lead to excessive wear and damages of the tap changer.

The tap changer function operates when it receives a “raise” or a “lower” command. The function expects an increase in tap changer position after a “raise” command. The tap changer control does not send more than one command at the same time. The change of position is verified and the blocking conditions are tested by the tap changer control before a consecutive command is sent to the tap changer.

The duration of the output pulse from the tap changer control to raise or lower the tap changer is adjustable. Default setting is 1 second. The number of operations of the tap changer is counted by two counters which may be set and reset by the operator. They can for example be used to count the total number of operations and the number of operations since the maintenance overhaul.

10.2. On-Load Parallel Control

The parallel control function for parallel control of OLTC's is designed to operate together with the single tap changer control as described before.

The parallel control uses the master/slave principle, meaning that the regulator of one transformer is active while the tap changer of the other transformer follows the changes of the first (master) transformer. The operator determines the control mode of every transformer or pair of transformers. This mode can be manual, automatic independent and automatic master/slave.

When tap changer position of parallel tap changers differs more than 1 step an alarm is generated immediately. When the difference is one step an alarm will be generated.

ABB B.V.
Marten Meesweg 5
NL-3068 AV Rotterdam
The Netherlands
Tel.: +31 10 4078 911
Fax: +31 10 4078 452

S.A. ABB N.V.
Hoge Wei 27
BE-1930 Zaventem
Belgium
Tel.: +32 2 718 65 19
Fax: +32 2 718 64 99