CHAPTER 4 AS-i OPERATION

4.1 AS-i Principle

4.1.1 Principle of Communication

The AS-i protocol is based upon a "Master/Slave" protocol. The AS-i master constantly polls all the slaves on the AS-i and sends them the output information it has received from the PLC. It also provides the PLC with the input information it has read. The guaranteed cycle time for this to be completed is fully deterministic. During normal operation (following the initialization and system start-up phases), the cycle time is typically 5 ms for up to 31 connected slaves. This cycle time will reduce with fewer slaves connected [8].

4.1.2 PLC Role

The PLC reads the input information provided by the AS-i master and writes these data to its input data field, after execution the control program it updates its output data field with the values derived from the control sequence. The length of the PLC cycle depends on the PLC and the length of the control program.

4.1.3 Master Role

As a general rule, the master manages the following functions:

- System initialization
- Identification of the connected slaves
- A cyclical transmission of data relating to slave parameters
- Ensuring the integrity of the normal cyclical data exchanges
- Managing the system diagnostics (operational status of slaves)
- Monitoring the condition of the PSU, etc.
- Communicating any errors detected to the system controller (PLC,..etc.)
- Reconfiguration of slave addresses should the system be changed in any way (for example: replacement of a slave module, etc.)

The "Master Profile" will define the individual capabilities of each type of "Master".

4.1.4 Master Profiles

Different profiles characterizing the performance have been defined for AS-i masters. For the further development of the slave functions, the new functions have also been integrated in the master profiles. Table 4-1 shows the different types of masters' profiles.

Table 4-1 Different AS-i Master Profiles

Profile	Functionality
M0	Only binary signal are transmitted No analogue signals are exchanged
M1	Like M0, in addition analogue signals are exchanged
M2	Cyclical data exchange and a cyclical AS-i Parameters
M3	Like M1,complemented by extended addressing mode (62 slaves)
M4	Like M3, complemented by data protocols for byte transmission

4.1.5 Slave Role

Slaves decode queries they receive and answer immediately to the Master. As for Masters, their function capabilities are defined by a "profile".

4.1.6 Slave Profile

The profiles mainly decide on the compatibility of the AS-i components. The profile consists of two figures separated by a dot. The first figure indicates the I/O configuration while the second one indicates the identification code (ID code). This profile must be specified in the data sheet. Both configuration and ID code are permanently stored in the slave by the manufacturer. To do so, 4 bits are available for each slave. These bits can be read by the master. It would of course be conceivable to assign all 16 possible combinations. But to ensure that the AS-i system remains open for further developments in the future the combinations are used sparingly.

It is important that when the information is defined, the measuring method or operating principle is not restricted. So it is possible at any time to replace, for example, an inductive proximity sensor by a photoelectric sensor. The I/O configuration describes the direction of the data bits as input or output or bidirectional [7]. Table 4-2 shows the I/O Configuration Code where IN=Input, OUT= output, I/O = Bidirectional, NONE=Not configured.

Table 4-2 I/O Configuration Code

Code(Hex)	D3	D2	D1	D0
0	IN	IN	IN	IN
1	OUT	IN	IN	IN
2	I/O	IN	IN	IN
3	OUT	OUT	IN	IN
4	I/O	I/O	IN	IN
5	OUT	OUT	OUT	IN
6	I/O	I/O	I/O	IN
7	I/O	I/O	I/O	I/O

Code(Hex)	D3	D2	D1	D0
8	OUT	OUT	OUT	OUT
9	IN	OUT	OUT	OUT
A	I/O	OUT	OUT	OUT
B	IN	IN	OUT	OUT
C	I/O	I/O	OUT	OUT
D	IN	IN	IN	OUT
E	I/O	I/O	I/O	OUT
F	NONE	NONE	NONE	NONE

The ID code shows whether a slave has no profile (F hex), or there are decentralized peripheral modules (0 hex) or defined intelligent sensors, actuators or modules (1 hex). A profile is a clear description of a device; not only in terms of its I/O but also defining which data bits are used for which functions. Profiles make devices "interoperable", so devices from any vendor work with each-other thus easing replacement without the need for further modifications [6]. Table 4-3 shows all the slave profiles that have been defined by the AS-i organization.

Table 4-3 Allocated Profile of AS-i slaves

Allocated profile	Description
X.0	Remote I/O
0.1	Double dual signal sensor
1.1	Single sensor
3.1	Double sensor/actuator
7.1	Analogue input/output profile (6 to 18 bit).
7.2	Extended analogue input/output profile (6 to 21 bit).
7.3	Integrated analogue input/output profile (16 bit, with integrated master support)
7.4	Integrated extended analogue input/output profile (16 bit).
7.B	Safety sensors (AS-i Safe)
X.A	Reserved for extended addressing of A/B slaves for V2.1
7.D	Relay motor control
7.E	Solid state motor control
8.1	Double dual signal actuator
B.1	Dual actuator with feedback

Allocated profile	Description
D.1	Single actuating with monitoring
X.F	Undefined, vendor specific devices

The introduction of AS-interface 2.1 extended the profile by a third digit, the ID_2_Code. It indicates for example whether a slave supports the peripheral fault.

4.1.7 Interaction Between PLC, Master and Slaves

Figure 4-1 shows the interaction between the AS-i master and the PLC. Operation takes place in two independent cycles, the PLC cycle and the AS-i cycle. The AS-i master constantly polls all the slaves on the AS-i and sends them the output information it has received from the PLC. It also provides the PLC with the input information it has read. This AS-i cycle takes a maximum of 5ms (for a V2.0 AS-i master).

Before executing the program, the PLC reads the input information provided by the AS-i master. The AS-i master presents the information in the same format as the I/O modules. The PLC therefore cannot detect whether I/O modules or AS-i are being used. This means that no additional software is required to access the by the AS-i master. When the program has been executed, the output information is written to the AS-i master. The length of the PLC cycle depends on the PLC and the length of the program [6].

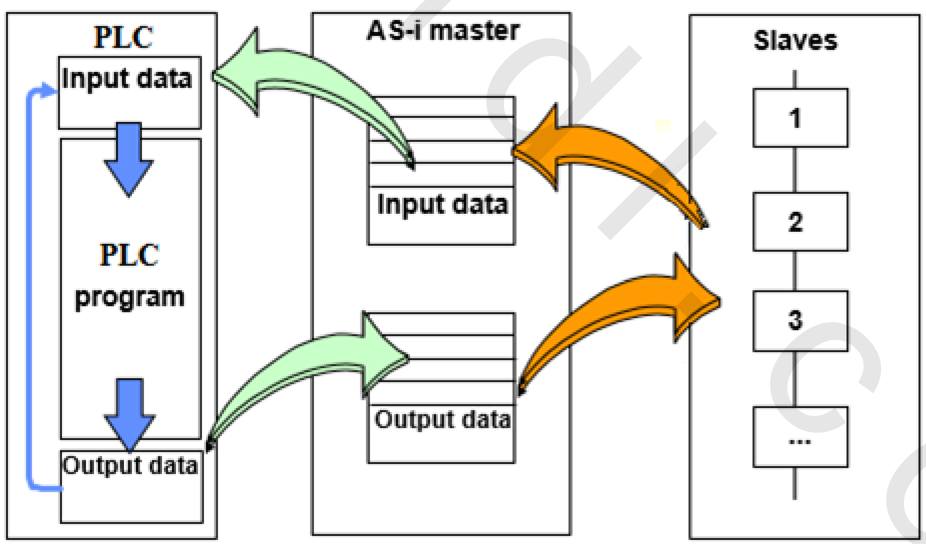

Figure 4-1 Interaction Between PLC, Master and Slaves

4.2 The Master Operating Phases

"Off line" Phase

The purpose of this phase is to set the different bus constituents into an initial state.

Detection Phase

The detection phase consists of detecting slaves present on the AS-i cable and memorizing their addresses and profiles.

Activation Phase

The activation phase consists of activating detected slaves for which the profile corresponds to the planned configuration.

Normal Operation Phase

This phase corresponds to normal operation of the network. Periodic data exchanges between the master and the slaves are as shown in Figure 4-2 [8].

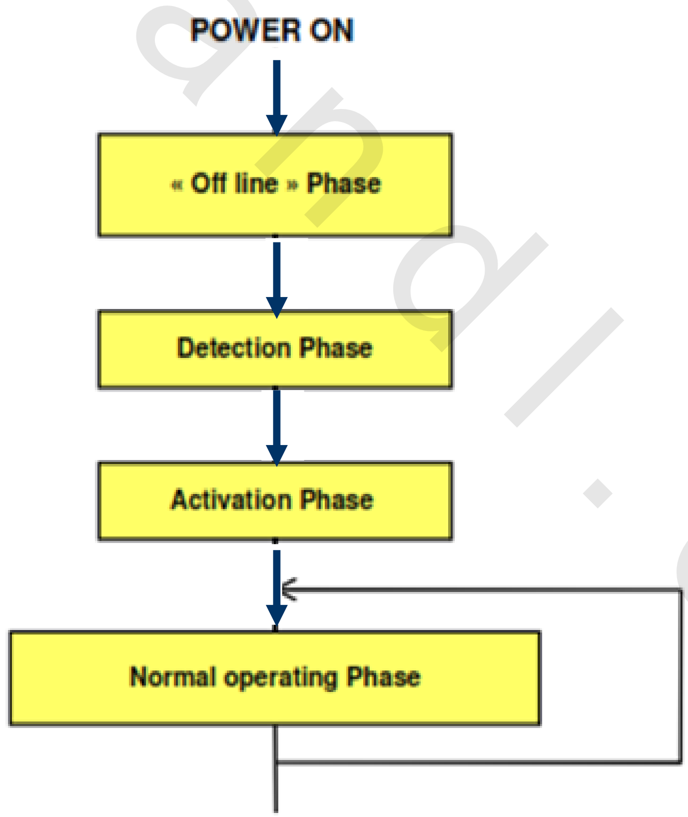

Figure 4-2 Master Operating Phases

4.3 Master / Slave Dialogue Elements

4.3.1 Master Tables

"Inputs" data image table (IDI)

This table contains data relating to the D0 to D3 data bits received back from each active slave on the system. Should any of the slaves be inactive, then the data in each relative part of the table will 0.

"Outputs" data image table (ODI)

This table contains data relating to the D0 to D3 data bits to be sent to each active slave on the system.

"Permanent parameter" data image table (PP)

This table contains data relating to the slave parameters as programmed (data held in non-volatile memory).When the system is restarted, this data is transferred to the PI table, as part of the initialization.

"Parameter" data image table (PI)

This table is used to store data relating to the P0 to P3 parameters which is sent to each slave (1 to 31).

"Permanent configuration" data image tables (PCD)

This table contains data relating to all the possible accessible configuration codes of the master and slaves. This data is held in nonvolatile memory within the master.

"Configuration" data image tables (CDI)

This table contains data relating to the I/O configuration and ID codes of all the slaves connected to the AS-i system.

List of prospective slaves (LPS) table

This table contains address and profile data for all the slaves that have been configured for use on the system and thus, those that should be present. These are termed "Prospective slaves".

List of detected slaves (LDS) table

This table contains address and profile data relating to all the slaves that are detected (or connected) on the system.

List of active slaves (LAS) table

Once the system starts up, it will look for all the prospective slaves. Any that are detected (recognized) on the system will be activated and all their relevant data will be stored in this table [8].

4.4 Slaves Mapping into the PLC

The inputs/outputs of all slaves are stored in an address field in the PLC. This address field consists of 16 bytes; two slaves (4 bits) are stored in one byte. The top 4 bits of the first byte contains the control information about the AS-i system. The base address depends on which slot is used for the AS-i master. With the first slot, this is byte 64, refer to Figure 4-3 for more illustration.

The following simple program illustrates how the assignment works:
A I65.2
= Q66.7
Input 65.2 is polled in this program. In the AS-i system, this input belongs to slave 3 (bit 2). Output 66.7 which is then set, corresponds to AS-i slave 4 (bit 3) [6].

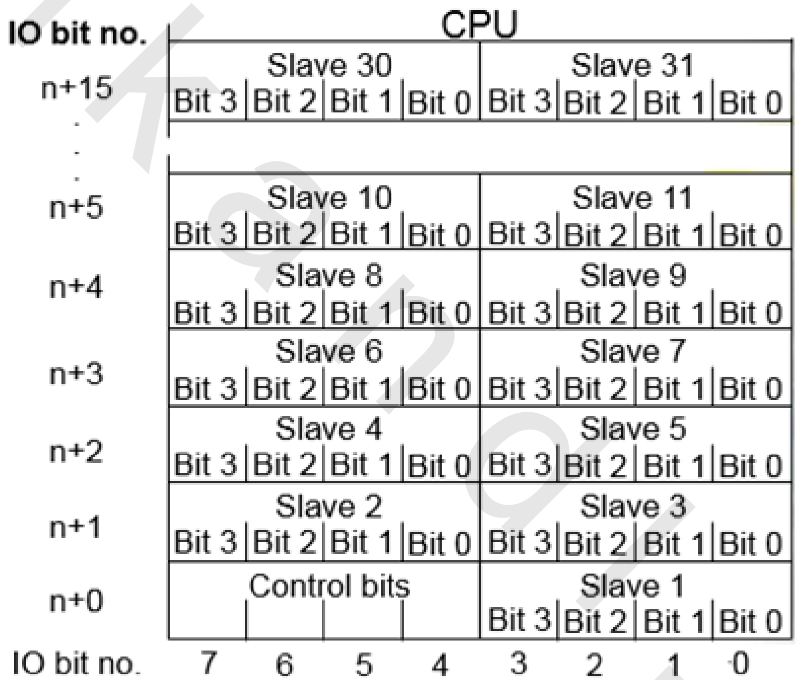

Figure 4-3 Slaves Mapping into the PLC

4.5 Operation of Slave/Master Dialogue

4.5.1 Signal coding

The AS-i data transmitters convert series of 0 and 1 into current pulses that will be converted into voltage pulses by AS-i cable, as shown in Figure 4-4.

These pulses are the result of a processing procedure which combines two types of signals:

- A differential "Manchester" code.
- Modulation based upon a type of alternating sine wave ($\sin^2$) [8].

Alternating pulse modulation (APM) is a method of serial transmission in base-band networks. The bit sequence to be transmitted is first recoded into a bit sequence that causes a phase shift every time there is a change in the transmitted signal. This generates a transmission current which, in conjunction with the inductor in the AS-i power supply, produces the required signal voltage level on the AS-i cable.

Each rise in the transmission current therefore results in a negative voltage pulse and each drop in the transmission current results in a positive voltage pulse. This method also enables signals with a higher voltage than the supply voltage to be generated very easily in the slave. This dispenses with the need for inductors in the slave, which reduces the size and cost of the electronics that need to be integrated into the sensor or actuator. At the receiving end these voltage signals on the AS-i cable are detected and converted back to the transmitted bit sequence [6].

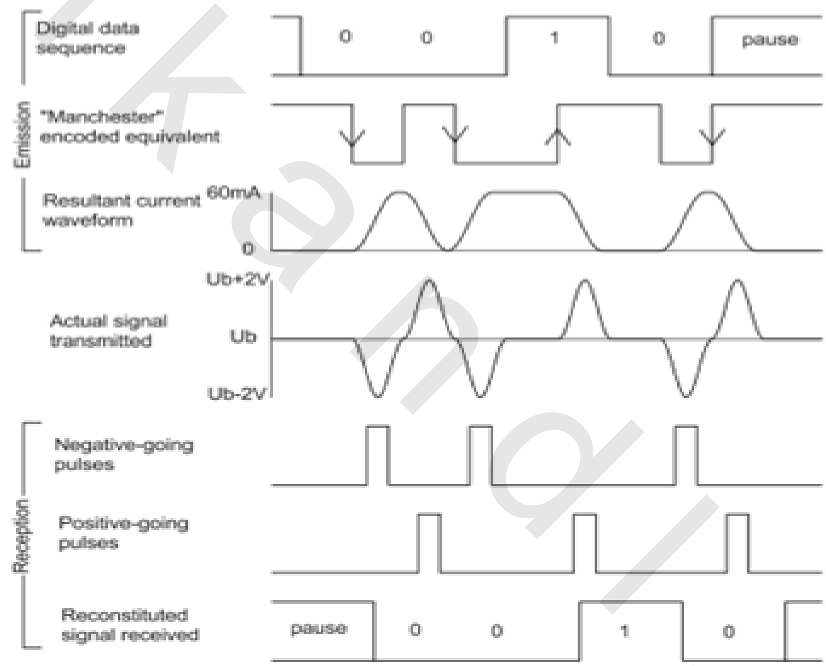

Figure 4-4 Signal Coding in AS-i

4.5.2 AS-i Data Packet

Data exchange between master and slaves is performed via telegrams (message frames). A telegram is a sequence of bits with a specific meaning assigned to them. AS-i has master telegrams that are sent by the master and slave telegrams that are returned by slaves.

A master telegram is 14 bits in length. The bits contain the address of the addressed slave (5 bits = 32 addresses) and the information to be transferred (4 bits of data). In addition, a control bit is reserved for specifying the type of call. The remaining bits are for error detection as shown in Figure 4-5 [6].

A slave telegram is 7 bits length. It is the response to the master calling the slave. This reply must be sent shortly after the master telegram (3 to 10 bit times). The slave reply is shorter as it is not necessary to transfer an address (there is only one master). Only 4 bits of data/parameters are transferred to the master. The remaining bits are used for error control purposes as shown in Figure 4-6.

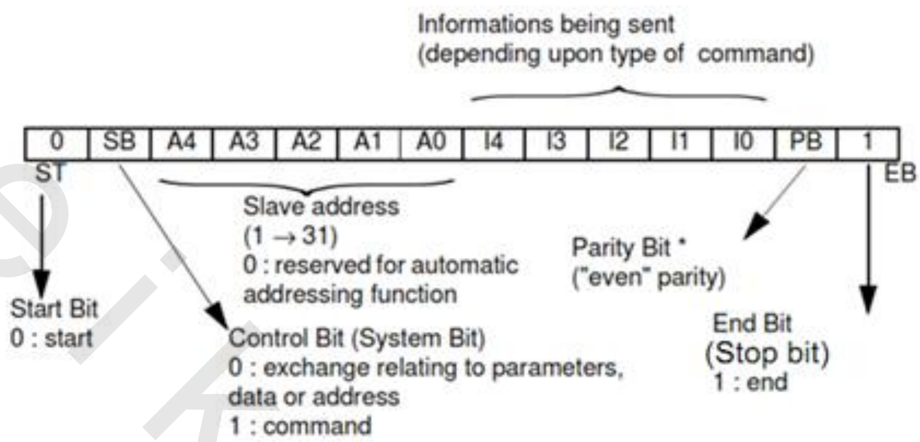

Figure 4-5 Structure of an AS-Interface Master Message

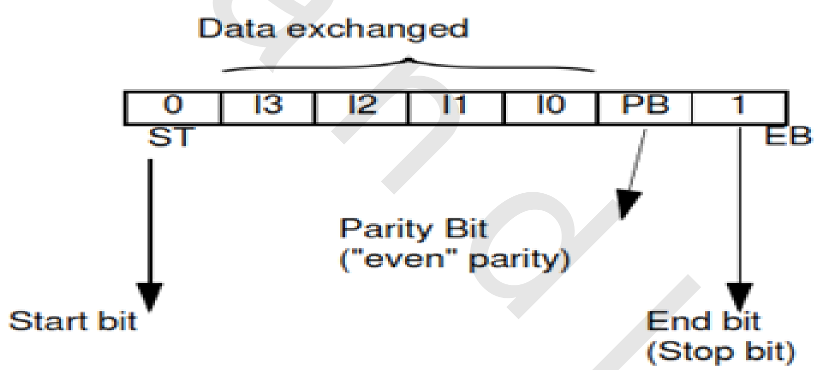

Figure 4-6 Structure of an AS-Interface Slave Message

4.5.3 The Different Phases

The master passes through four phases [8]:

4.5.3.1 <u>The initialization phase</u>

Initialization occurs whenever the master is powered-up or reset and this phase will ensure that all the data tables (buffers) within the various AS-i system components (master, slaves, etc.) are initialized. The initialization phase is executed in the following sequence:

1) The slave "input" image tables are reset to 0 (Input table = 0). This does not mean that this represents the real status of the associated sensors and actuators on the bus.

2) The slave "output" image tables are reset to 0 (Output table = 0). This also does not mean that this represents the real status of the associated sensors and actuators on the bus.
3) Any predefined parameters are stored by each slave, in its appropriate buffer.
4) The LDS table is reset to 0.
5) The LAS table is reset to 0.
6) The configuration reference table indicates that the configuration is invalid (FF_{HEX}).
7) The "Config. OK" indicator is reset to 0.
8) The indicator authorizing the "data exchange phase" is reset to 0.

4.5.3.2 The start up phase

The detection phase comprises the interrogation of each slave on the system, and the storing of their respective address and profile. Figure 4-7 describe the sequence of the startup phase. The AS-i master reads the I/O and the configuration data of the slaves connected on the bus, if this data is read correctly the AS-i master store the slave address in the LDS table and the I/O and the configuration data in the CDI table. If there was an error in reading the slave data, the AS-i master polls the slave again to capture its parameters as shown in Figure 4-7.

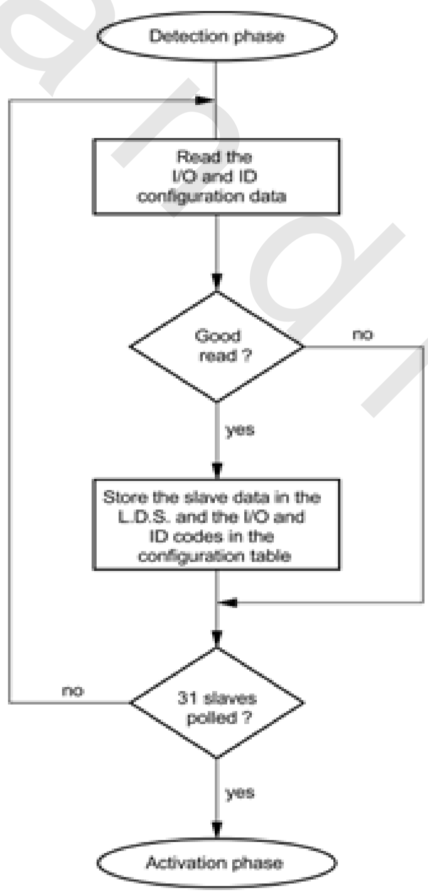

Figure 4-7 AS-i Bus Startup Phase

4.5.3.3 The activation phase

The bus master can operate in either of two distinct modes as shown in Figure 4-8:

- "Configuration mode": In this mode, all slaves connected to the bus will be activated. No account is taken of any differences between the "prospective" slaves and those actually connected. In this mode, no automatic addressing is possible.
- "Protected mode": This is the mode adopted by most systems, whereby the master will only activate those slaves which figure within the prospective system configuration and are recognized on the system. This is the only mode where automatic addressing is possible.

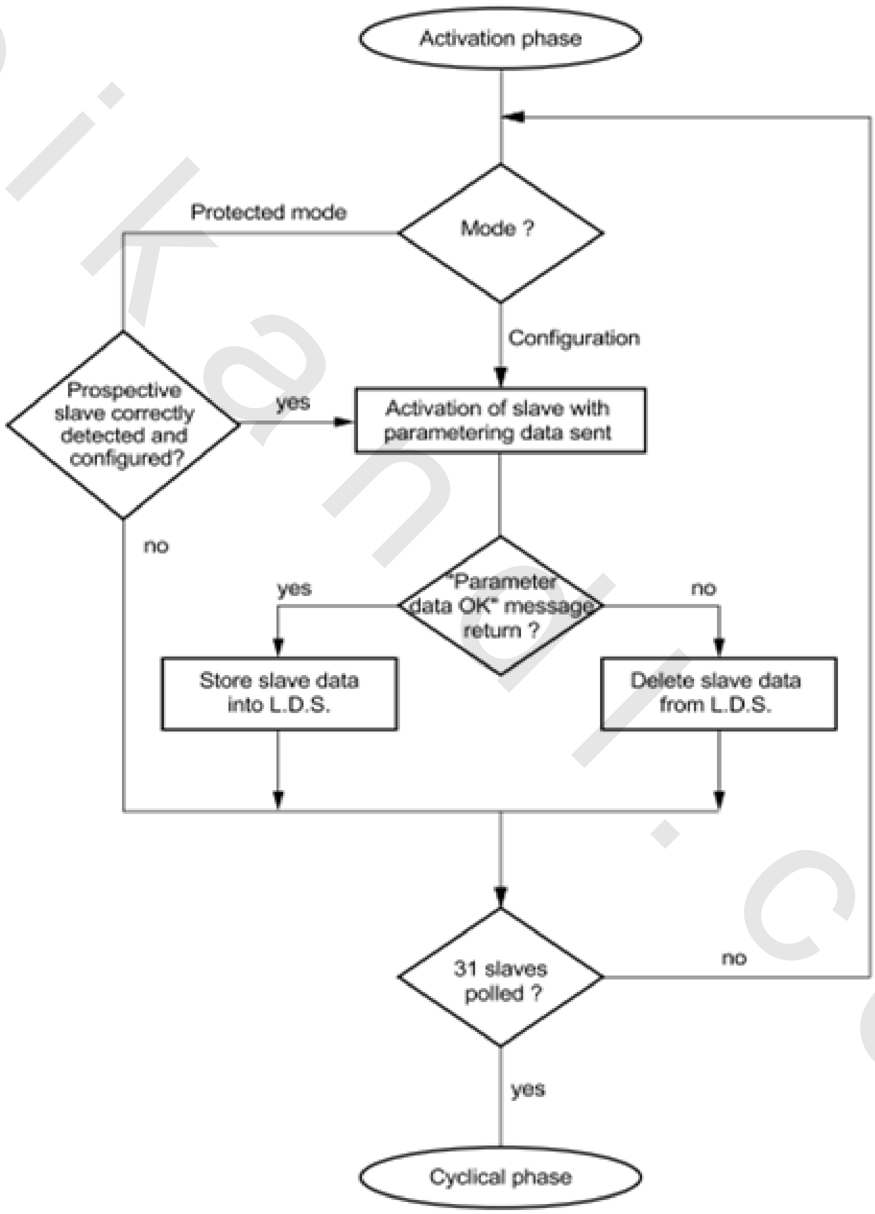

Figure 4-8 AS-i Bus Activation Phase

4.5.3.4 <u>The normal operating phase</u>

This fourth phase is the normal operating mode of the AS-i bus system and consists of regular cyclical communication between the master and all the slaves, this being achieved with a maximum cycle time of 5ms with 31 slaves being polled in V2.0 and with a maximum cycle time of 10ms with 62 slaves being polled in V2.1& V3.0. Each cycle has three stages:

a) Data Exchange Phase is the ongoing communication between the master and the slaves. If the data exchange is unsuccessful, three more attempts can be made during the next three cycles. After three failures, the system will assume that the slave has become faulty or absent. Its relevant data will be deleted from the "Active" and "Detected" tables and its "Input" image table will be reset to 0. A typical exchange with each slave takes about 156 µs, so if the maximum of 31 slaves were connected, the whole cycle would only take: 31 x 156 µs = 4.84 ms (thus < 5 ms).

b) System Management Phase, after completion the data exchange phase, the master may send other command messages to the slaves. Each transaction is unique and cyclical, which means that it only occurs during a normal operating cycle and the master can only send one particular command to one particular slave at any instant. So, the par metering phase of the 31 slaves will take: 31 x 5 ms = 155 ms.

   These messages are, for example:
   - Writing par metering data
   - Reading operational status
   - Reading a slave configuration
   - Reading a slave address (ID) code
   - Assigning a slave address (ID) code and Resetting, etc

c) Update /Slave Introduction Phase, after the completion of the management phase, the master instigates an update/slave introduction phase to check for any new slaves on the bus. The master interrogates each slave in turn (addresses 0 to 31) to check each I/O configuration and ID. In the worst case, any new slaves will be detected by the time the system has completed 31 cycles (polled around a maximum of 31 addresses).

   If a new slave is detected, then 3 more cycles will be required to:
   - Read the I/O configuration
   - Read the ID code
   - Send any par metering data

   The maximum period required to introduce a new slave during this phase is 170 ms, i.e. (31 cycles × 5 ms) + (3 × 5 ms) = 170 ms. The principle of comparing the various tables of configured, prospective and detected slaves is again used to activate the new slave [8].

4.6 Summary

The AS-i network operation is based upon a "Master/Slave" protocol. The master has different phases of operation and contains different tables in its memory. Each table contains the data bits received back from each active slave on the system. The AS-i system messages which are sent by the master and returned by slaves have a specific structure and signal coding.