

SIMPLIFYING INDUSTRIAL PROCESS CONTROL USING LINKED STATE MACHINE APPROACH

K.A. Akpado, H.C. Inyama, C.C. Okezie
Department of Electronic & Computer Engineering
Nnamdi Azikiwe University, Awka

Abstract

The use of microcontrollers in the design of embedded industrial process control systems is limited by the level of complexities involved in actualizing desired control automation. Adding intelligence and self diagnostic features to such systems usually increase the complexity of the machine. This paper studies the *Linked-State Machine* approach as a design alternative to overcome the challenges of designing complex industrial process control systems. The complexity of an intelligent class C water level and temperature control system with self diagnosis is simplified by breaking the system into three simpler class A machines. Each of the three simple machines is designed separately as embedded systems working from their Algorithmic State Machine (ASM) charts. The three simple machines are then linked together as State Machines to actualize the desired operation of the original complex system.

Keywords: Algorithmic State Machine (ASM), State Transition Table (STT), ROM, *Linked-State Machine*.

1.0 Introduction

Intelligence is the degree of reasoning and learned behavior and in the context of process control system design, the system's ability to accept the user's statement of goals and carry out the tasks delegated to it [1]. A minimum level of intelligence may involve some statements of preferences, perhaps in the form of rules, with an inference engine or some other reasoning mechanism to act on the preferences. High levels of intelligence include a user model or some other form of understanding and reasoning about what a user wants done and planning the means to achieve the goal [2]. Further up on the intelligence scale are systems that learn and adapt to their environment, both in terms of the user's objectives and in terms of the resources available to the agent and exploit these in anticipating and satisfying user needs [3].

Industrial intelligence suggests that a system of industrial process should be designed to exhibit well defined level of automation that should ensure the following:-

- Accurate monitoring of the process involved.
- Self diagnosis in the event of fault.

In designing an intelligent process control system, a number of design approaches can be adopted. The level of intelligence built into the system determines the complexity of the machine, which determines the most suitable approach to use.

A simple microcontroller based design can achieve a very good level of automation and intelligence, but will lead to a lot of complexity with higher level of intelligence. A good

approach to ease the design of complex systems is to break the system into a number of smaller systems (or subsystems) which can be linked together to give the desired intended system [5,6].

2.0 A Typical Process Control System

Consider a complex process control system, where the parameters of interest are liquid resource level and temperature. The process control system is expected to be equipped with a microcontroller based liquid level and temperature control system as well as automatic self-diagnostic features. This system is expected to serve an industrial set-up where a reservoir tank supplies a feeder tank from which water can now be dispensed or collected at a given temperature. As already stated above, the system should be equipped with some level of intelligence to enable it detect when a faulty condition occurs in the process flow and even suggest possible solution(s). i.e. it will have self diagnostic capabilities. Figure 1 illustrates a typical complex process control system with the desired features while figure 2 shows the ASM chart representation of the system operation.

The rectangular boxes in the ASM chart of figure 2 represent the states in the process control system, and each rectangular box has its state name at its lower left-hand corner. The process control flow is as follows:

State 0 (ST0): The controller checks if upper Tank (or reservoir) is low or running short of water (UTNKL). If so, it displays a visual alarm showing that upper Tank is empty (UTNKEMPTY). It then waits in that condition

(STI) until a signal (UTNKRST) comes to show that upper Tank is no more empty (ie it has been refilled). At that point the process control returns to state 0.

If at state 0 (ST0) the process controller finds that the upper tank is not empty, it checks if it is now at its middle level. If so, it triggers a warning audible alarm (UMDLTRG) to forewarn operators and move on to state 2 (ST2). If the upper tank level is above middle, the control system still moves on to state 2 (ST2) but without triggering the middle alarm

At state 2 (ST2), the controller checks if the lower Tank level is low. If so, it triggers a timer and turns high valve 1 (HVALVE1) so as to dispense water from upper tank into lower tank. If the timer times out without the lower tank level getting to some middle position above low, a valve 1 fault (VLV1FLT) is indicated (ST5) to signal that valve 1 is not functioning. If the lower tank content has moved to some middle level above low, the control moves to state 4 and leaves valve 1 ON until lower tank is filled (LTNKH).

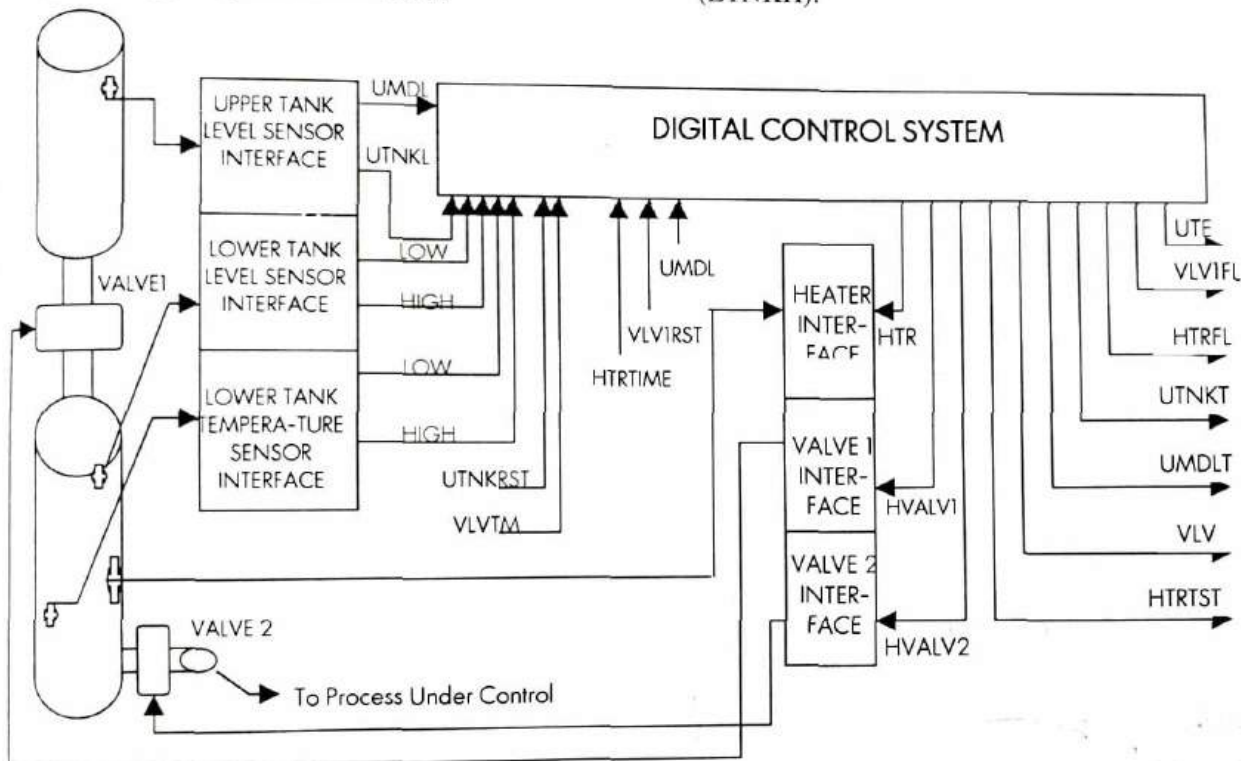


Figure 1: Illustrating a complex process control system

When all is well with the lower tank liquid level, the control system moves into state 6 (ST6). Here it checks if the temperature of lower tank content is low (TEMPL). If so, it triggers a timer and turns the heater on. If the timer times out and the lower tank temperature has not moved to some middle position above lower, a heater fault error is indicated (HTRFLT or ST8) otherwise the controller moves to state 9 and leaves the heater ON till the liquid temperature of the lower tank is high (LTNKH). Once the level of the liquid in the lower tank and its temperature are both okay, the control system moves to state 10 (ST10) where valve2 is turned ON (HVALVE2) to allow the process under control to receive water. Also if while in state 10, the liquid temperature in the lower tank goes low, the controller goes back to state 0 to remedy the situation. Similarly if the

liquid temperature becomes low, the controller goes back to state 7 to try and remedy it.

In effect, the ASM chart of fig.2 has six state outputs namely UTKEMPTY, HVALVE 1, VLV1FLT, HEATER, HTRFLT and HVALVE 2. In addition to the outputs, it also has four conditional outputs namely:- UTKNTRG, UMDLTRG, VLVITST and HTRTSTTRG.

It is important to note at this point, that it is on these four conditional outputs that the intelligence and self diagnostic features of this control system are anchored.

The machine of figure 2 falls into Class-C machines [1]. Developing such machines using the present approach will be very hard to actualize as it presents a very complex

system to be handled by available design features.

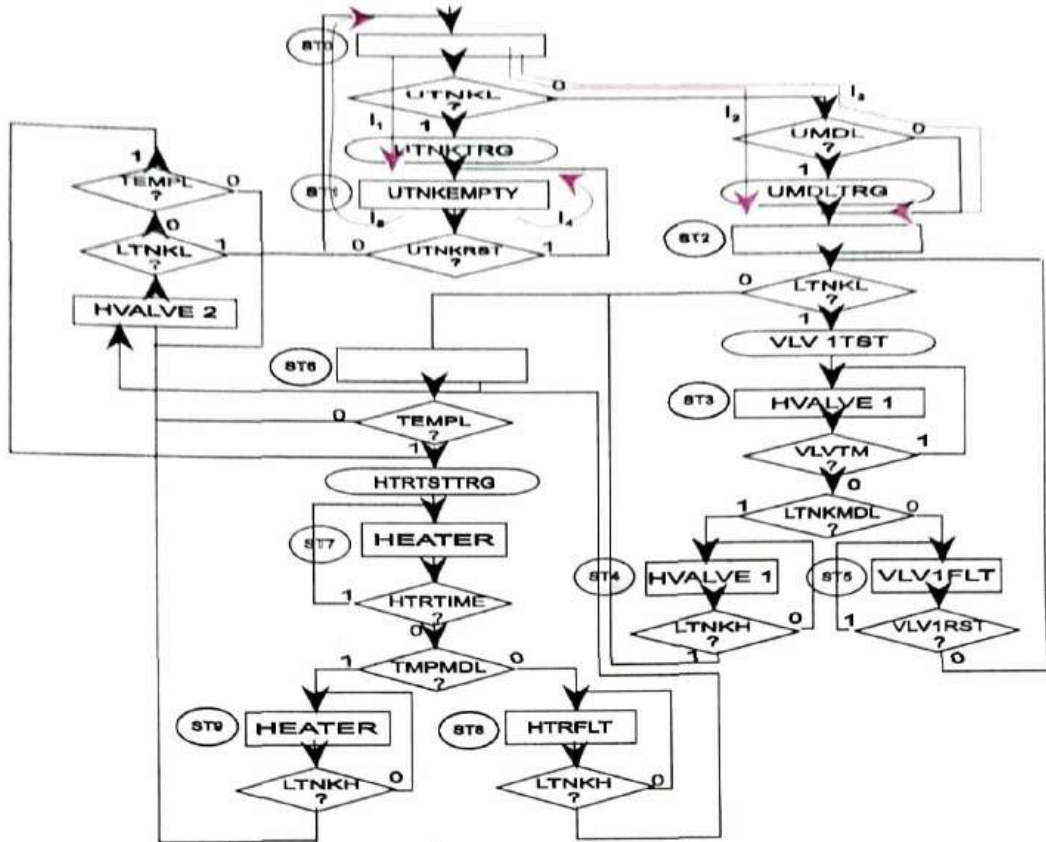


Fig. 2: Automatic / Intelligent water level and Temperature process control system with self diagnostic features.

3.0 *Linked State Machine Approach*

It is possible to break the complex Class-C machine represented by the ASM chart of fig2 into simpler machines of Class-A category and then link the simple machines together to actualize the overall operation of the original complex machine. The machine represented by the ASM chart of figure 2 can be separated into three simple machines as follows:-

1. The upper tank control system.
2. The lower tank control system.
3. The heater control system.

Each of these three simple machines can now be developed with each fully automated and intelligent enough to handle diagnostic features. The three can then be linked together to effect full operation of the complex machine earlier conceived.

4.0 The Upper Tank Control System

The upper tank control system is designed to monitor the state of the upper tank that constantly supplies the lower distribution tank with water whenever it is needed. It is therefore expected that the system should be able to monitor the state of the valve that controls its supply and report eventual fault conditions and also know when to supply water to the lower tank.

This system would be designed by developing the ASM chart representation of its operation as well as the State Transition Table that would define the Link Paths of the subsystem's state transitions. The "Location Content" and "Location Address" for the systems programming can then be determined from the expanded STT. Figure 3 shows the ASM chart of the Upper Tank Control System while tables 1 and 2 show

the State Transition Table (STT) and Fully Expanded STT, defining the Link Paths for

the system. Some of the Link Paths are indicated in the ASM

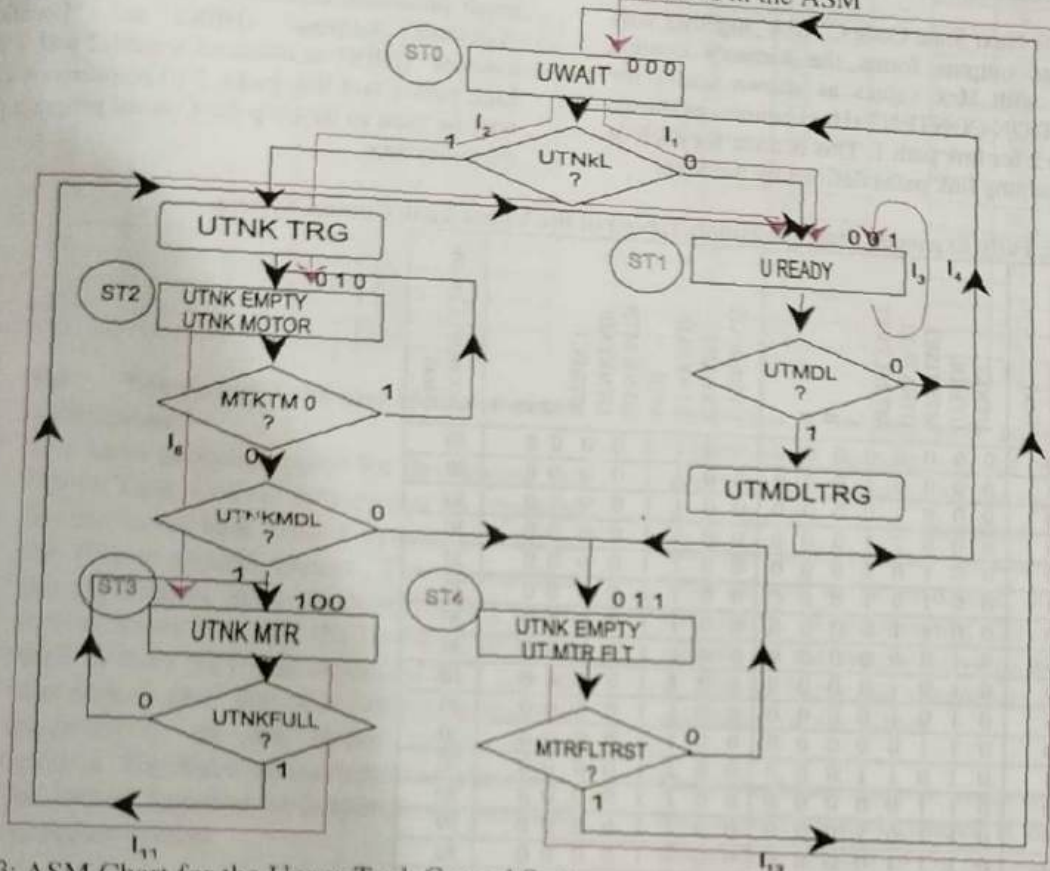


Fig.3: ASM Chart for the Upper Tank Control System

4.1 Expanded State Transition Table For The Upper Tank Control:

For a ROM based design approach, the above STT of table 1 should be expanded to accommodate all the possible states of the system based on the outputs of the input qualifiers, thereby taking care of all the dashes in the STT.

In other words, for all the places where the outputs of the input qualifiers are represented by dashes, on the STT, we replace them with either 0 or 1. The input qualifiers, together with the present state code CBA form the ADDRESS pattern for the ROM with Hexadecimal values as shown under the LOCATION ADDRESS.

Table 1: State Transition Table For Upper Tank Control

LINK PATHS	UTKNKL UTKMDL MTRTIMO UTKNFULL MTRFLTRST	PRE-SENT STATE NAME	PRES- ENT STATE CODE CBA	NEXT STATE NAME	NEXT STATE CODE C ² B ¹ A ¹	UTKNWAIT UREADY UTKNEMP/MTR UTKN MTR UTKNEMP MTRFLT
L1	0 - - - -	ST0	000	ST1	001	10000
L2	1 - - - -	ST0	000	ST2	001	10000
L3	- 0 - - -	ST1	001	ST1	001	01000
L4	10 - - -	ST1	001	ST2	011	01000
L5	- 1 - - -	ST1	001	ST1	001	01000
L6	11 - - -	ST1	001	ST2	011	01000
L7	- - 1 - -	ST2	011	ST2	011	00100
L8	- 1 0 - -	ST2	011	ST3	010	00100
L9	- 0 0 - -	ST3	010	ST4	110	00100
L10	- - - 0 -	ST3	010	ST3	010	00010

L11	- - - 1 -	ST 3	0 1 0	ST 1	0 0 1	0 0 0 1 0
L12	- - - 0 -	ST 4	1 1 0	ST 4	1 1 0	0 0 0 0 1
L13	- - - 1 -	ST 4	1 1 0	ST 0	0 0 0	0 0 0 0 1

Also, the Next State Code C' B' A' together with the state outputs forms the memory content pattern with Hex values as shown under the LOCATION CONTENT (Hex) column as shown in table 2 for link path 1. This is done for each of the remaining link paths defined by the State

transitions of the system's dynamics and the result presented in table 3. The contents of the "Location Address" (HEX) and "Location Content" (HEX) as obtained in table 2 and 3 for Link path 1 and link paths 2-13 respectively can now be used to develop the Control program for the subsystem.

Table 2: Fully Expanded State Transition Table For the Upper Tank Control System.

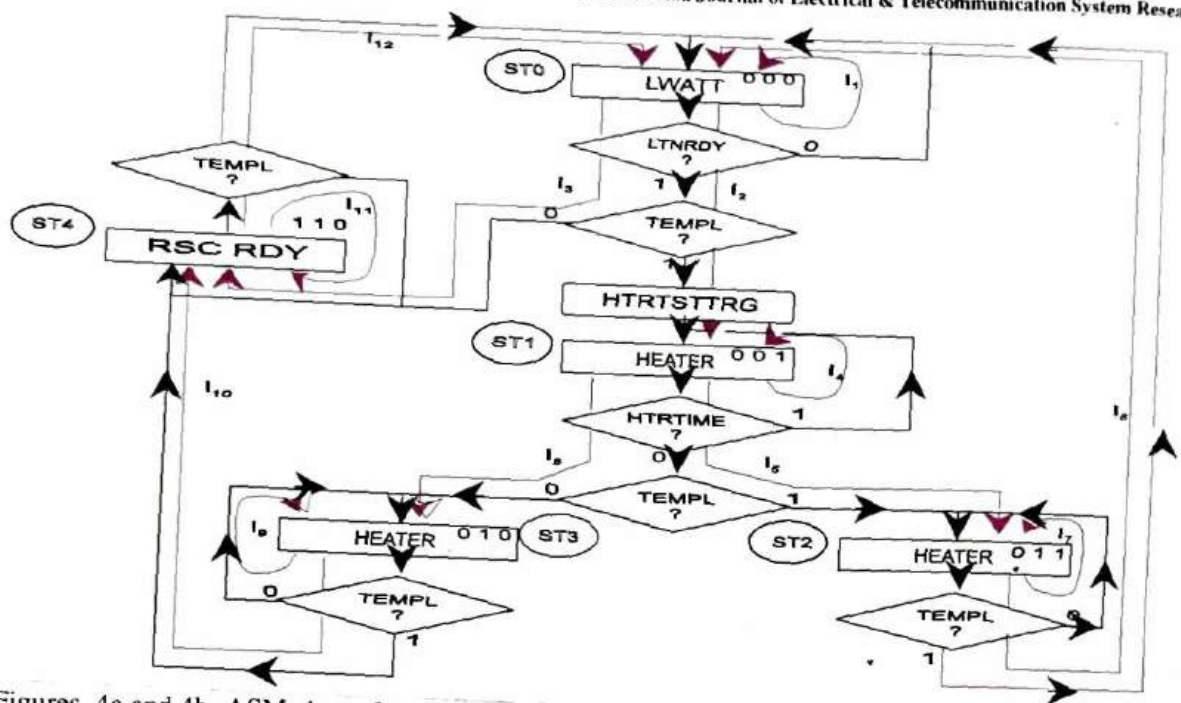
LINK PATHS	Location Address (Hex)	UTNKL UTMDL MTRIMO UTNKFULL MTRFLTRST	C B A	UTNKWAIT UREADY UTNKEMP MTR UTNK MTR UTNKEMP MTRFLT	C B A	Location Content (Hex)
L1	00	0 0 0 0 0 0 0 0 0		0 0 1 1 0 0 0 0		30
	08	0 0 0 0 1 0 0 0 0		0 0 1 1 0 0 0 0		30
	10	0 0 0 1 0 0 0 0 0		0 0 1 1 0 0 0 0		30
	18	0 0 0 1 1 0 0 0 0		0 0 1 1 0 0 0 0		30
	20	0 0 1 0 0 0 0 0 0		0 0 1 1 0 0 0 0		30
	28	0 0 1 0 1 0 0 0 0		0 0 1 1 0 0 0 0		30
	30	0 0 1 1 0 0 0 0 0		0 0 1 1 0 0 0 0		30
	38	0 1 0 0 0 0 0 0 0		0 0 1 1 0 0 0 0		30
	40	0 1 0 1 0 0 0 0 0		0 0 1 1 0 0 0 0		30
	48	0 1 0 1 0 0 0 0 0		0 0 1 1 0 0 0 0		30
	50	0 1 1 0 0 0 0 0 0		0 0 1 1 0 0 0 0		30
	58	0 1 0 1 1 0 0 0 0		0 0 1 1 0 0 0 0		30
	60	0 1 1 0 0 0 0 0 0		0 0 1 1 0 0 0 0		30
	68	0 1 1 0 1 0 0 0 0		0 0 1 1 0 0 0 0		30
	70	0 1 1 1 0 0 0 0 0		0 0 1 1 0 0 0 0		30
	78	0 1 1 1 1 0 0 0 0		0 0 1 1 0 0 0 0		30

Link paths	Location Address (Hex)	Location Content (Hex)
L2	80	70
	88	70
	90	70
	98	70
	A0	70
	A8	70
	B0	70
	B8	70
	C0	70
	C8	70
	D0	70
	D8	70
	E0	70
	E8	70
	F0	70
	F8	70
L3	01	28
	09	28
	11	28
	19	28

	21	28
	29	28
	31	28
	39	28
	81	28
	89	28
	91	28
	99	28
	A1	28
	A9	28
	B1	28
	B9	28
L4	81	68
	89	68
	91	68
	99	68
	A1	68
	A9	68
	B1	68
	B9	68
L5	41	28
	49	28
	51	28
	59	28

	61	28
	69	28
	71	28
	79	28
	C1	28
	C9	28
	D1	28
	D9	28
	E1	28
	E9	28
	F1	28
	F9	28
L6	C1	68
	C9	68
	D1	68
	D9	68
	E1	68
	E9	68
	F1	68
	F9	68
L7	23	64
	2B	64
	33	64
	3B	64

	63	64
	6B	64
	73	64
	7B	64
	A3	64
	AB	64
	B3	64
	BB	64
	E3	64
	EB	64
	F3	64
	FB	64
L8	43	44
	4B	44
	53	44
	5B	44
	C3	44
	CB	44
	D3	44
	DB	44
L9	02	C4
	0A	C4
	12	C4
	1A	C4



Figures. 4a and 4b: ASM charts for the Lower Tank and Heater Control Systems

6.0 Linking The Subsystems

Having developed the three subsystems as three separate simple machines, each fully equipped with adequate intelligence and self diagnostic features that will ensure complete

functionality of the original complex system, the three simple machines can now be linked together to function as one complete system. Block diagram of the resultant Linked State Machine is shown in figure 5.

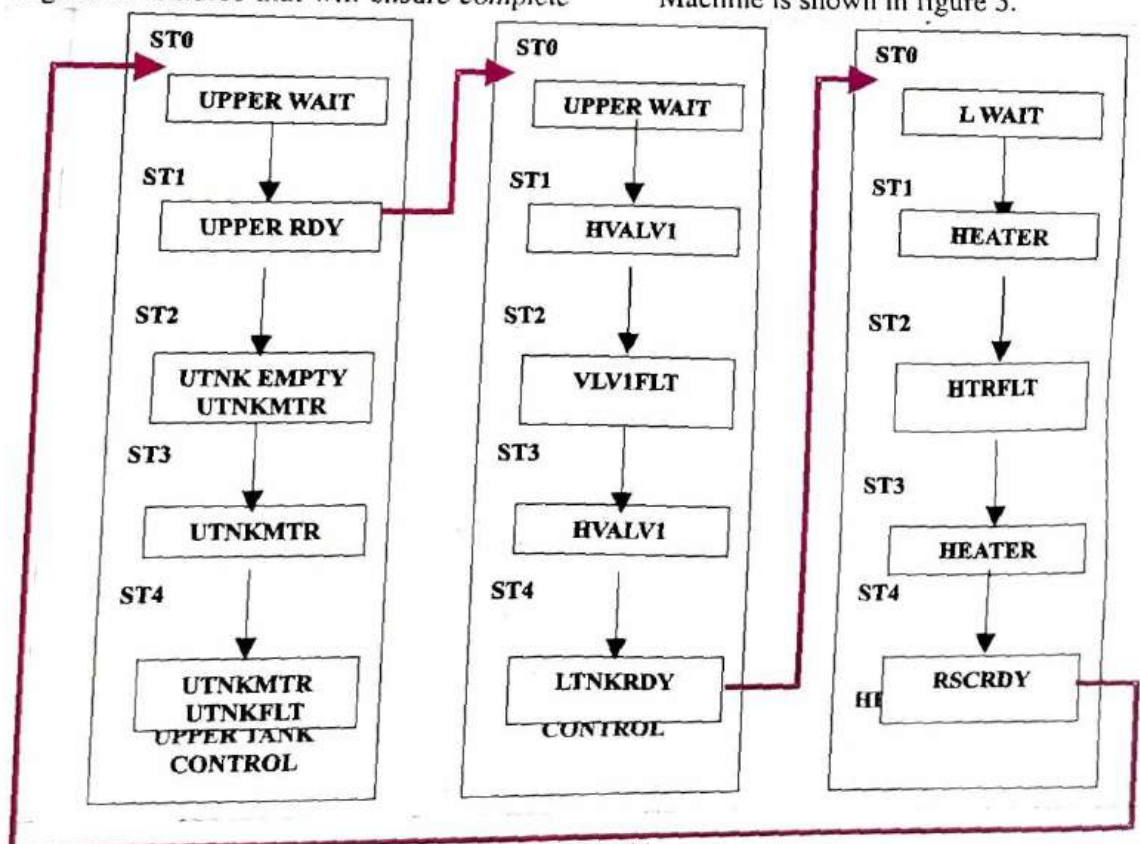


Fig. 5: Block diagram of the System as Linked State Machine.

7.0 Conclusion

A detailed approach to the design of complex industrial process control system is presented to show how machine complexities can be simplified in design. Increase in the functional features of control systems increases the complexities of such system and when such is the case, it is possible to break such machine into subsystems of simpler machines which can now be linked together to actualize the full potential of the originally intended system.

The author presented a detailed example showing how giving parameters of interest in a typical process control system were monitored and controlled by separate simple control systems which are now linked together to bring about a complete process control system.

Although linked-state machine approach in design of process control systems suggests the development of multiple systems with implications of higher cost of production and resource usage, it is a very efficient way of dealing with machine complexities which would have been very difficult to handle.

References:

- [1] Inyama H.C and Okezie C.C, designing microcontroller based universal process control systems; *Electroscope: international journal of Electrical & Telecommunication systems Research*, November, 2007, pp.11-26.
- [2] C.R Clare, *Designing logic systems using state machines* (U.K MacGraw-Hill, 1973).
- [3] Mancharka A.V, Behere S.H, Intelligent Universal Sensor Interface development using microcontrollers, Dept. of Electronic Science, NAC & S.C College Alimednagar, India, 2005.
- [4] Ingham, M.D, Rasmussen, R.D, et.al. "Engineering Complex Embedded Systems with State Analysis and the Mission Data System", AIAA Intelligent Systems Technical Conference, Chicago, IL, 2004.
- [5] Sights*, G. Ahuja, G. Kogut, E.B. Pacis, H.R. Everett, D. Fellars, S. Hardjadinata Modular robotic intelligence system based on fuzzy reasoning and state machine sequencing, Space and Naval Warfare Systems Center, San Diego 53560 Hull Street, San Diego, CA 92152
- [6] Melin, P. and Castillo, O., *Hybrid Intelligent Systems*, Springer-Verlag Berlin Heidelberg, New York, NY, 2005.
- [7] H.C Inyama, Unpublished Project Notes on Process Control Simulation, Department of Electronic and Computer Engineering, Nnamdi Azikiwe University Awka, 2010.
- [8] H.C Inyama, Unpublished Lecture Notes on Microcontroller based Process Control Systems, Department of Electronic and Computer Engineering, Nnamdi Azikiwe University Awka, 2010.