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Centralized monitoring and control of air conditioning units

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A virtual instrument has been developed using LabVIEW graphical programming language to monitor current drawn by air conditioning units (ACUs) at a central location. Program is flexible and permits operator to control, override and limit operational time of individual units so that wasteful expenditure is avoided. Concurrently, in the event of a power outage, load on back up DG sets can be programmed and restricted only to areas of emergency. Minimal hardware changes are required for implementation of new design system in existing ACU installations. Substantial reduction in cabling cost is achieved by designing additional hardware to reduce number of cables, connecting data acquisition card to AC systems.

Keywords: Air conditioning, Data acquisition, HVAC, LabVIEW, Virtual instrument

Introduction

Energy consumed by air conditioning units (ACU) varies widely and depends on time of usage, prevailing local environment, temperature settings and application necessities[1,2]. Currently, only a few commercial products are available to monitor heating, ventilation and air conditioning systems (HVAC) in buildings. Liew[3] has explored possibility of using X-10 and Internet to control home ACs. Colak *et al*[4] have described a fully integrated system using a microcontroller, an IR remote control device, a web camera and a LCD to remotely monitor and control ACUs. Some other studies[5] have been directed at optimization of cooling systems rather than energy monitoring.

This paper describes a virtual instrument (VI), which can be integrated into any ACU setup with minimum additional hardware and minimal changes in power cabling scheme. Data acquisition and control is carried out entirely by a single computer.

Proposed System

Basic System

Basic system (Fig. 1) comprises of five components [a PC loaded with LabVIEW 8.0 software, a NI make DAQ card with 16 Analog inputs, 2 analog outputs & 24 digital I/O's, a solid sate relay (SSR) and a current transformer (CT)]. Incoming power for AC is interrupted and channeled through a SSR and a CT. Such a connection scheme adapts very well in locations where an AC is already functioning from a common bus, as it implies minimum changes in power circuit. CT output points are brought out to an analog input channel of DAQ card while control input points of SSR are connected to a digital output channel of same card. Thus, only two additional pairs of signal cables are required from local AC point to monitoring and control system. Lab ˜VIEW graphical programming language is utilized to develop a VI to achieve following scheme:

Step 1

Front panel (user interface) of VI permits operator to enter switch ON and OFF times for operation of AC;

Step 2

If real time falls within entered time zone, VI sets a digital output to switch ON SSR and logs analog output of CT and real time in an Excel compatible file;

Step 3

If real time is outside zone, AC is not switched ON and data logging is suspended. Program waits at Step 2;

Step 4

Once AC is ON, program checks whether 'real time OFF' value has timed out or not;

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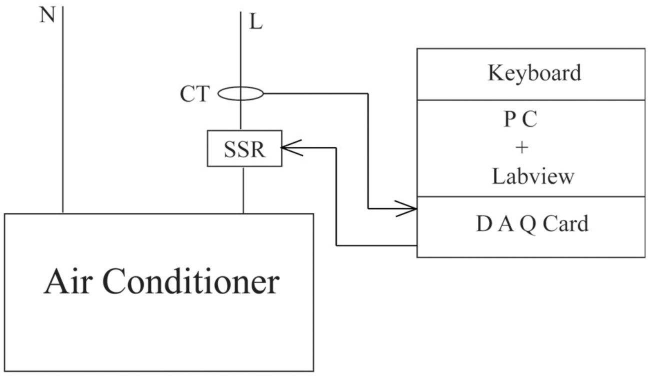

Fig. 1—Basic functional diagram of system

Step 5

If time is over, AC is shut off; and

Step 6

If time is not over, program waits for a change in measured CT output. This happens, for example, when temperature set for AC has been attained, in which case compressor is switched off while blower continues to run. When such a quantum change is observed, new value of current is logged in same Excel compatible file. This process repeats itself over and over again from Step 4.

Localized Multichannel Operation

Basic scheme can be extended to include more AC units by using an additional CT and SSR for each ACU. Input & output signals can then be routed to additional channels of same DAQ board (Fig. 2). After gathering data from first channel, rest of 15 channels is serviced one by one. Measured current values are stored in separate files, one for each AC unit. The scheme requires at least four data cables for each AC. Thus, for 16 ACs, number of cables works out to be 64. Thus, an increase in number of ACs leads to a corresponding increase in overall cost of total arrangement. This increase is escalated further if location of ACs is far from monitoring PC, because in such a case, use of shielded cables is obligatory to prevent inter cable noise interference.

Another factor related to multichannel processing is sampling interval for each channel. Since channels are processed sequentially, sampling time increases with number of ACs monitored. A built in timer in most AC systems prevents from energizing AC until a minimum time (3-5 min) has elapsed from the time it shut off last. Such delays in AC systems are typical and thus sampling times can be high, of the order of minutes. Such sampling intervals are easily achievable in practice.

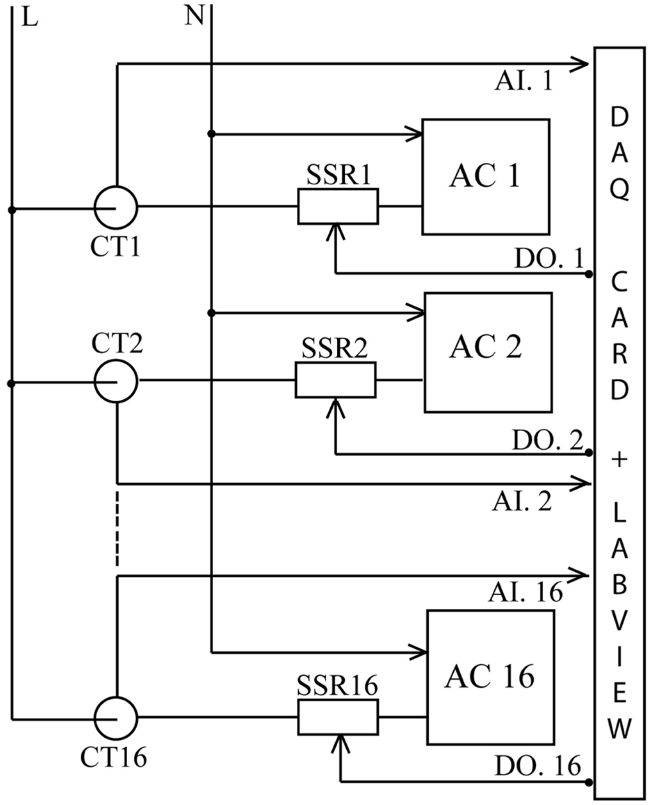

Fig. 2—Functional set up for data acquisition

Remote Monitoring for Acquiring Data from AC Systems, Separated by Large Distances

For a large complex, where ACs are distributed over a wide area in different working groups, cable cost will be overbearing. In order to reduce the number of data cables and hence their cost, a multiplexing arrangement, (Fig. 3) has been designed to serve an organization like a hospital or factory. Organization is divided into working groups or nodes that represent buildings or departments, which in turn are subdivided into individual channels that represent ACs within the group. Input circuit for acquiring CT data is shown on the left. Output circuit for switching on SSRs is shown on the right (Fig. 3). Components U2 to U9, MUX1.1 to MUX16.4 and U10 to U20 are all located on same PCBs, which are placed at each node or work group. However, single IC U1 is located near DAQ card and PC. This scheme is designed to gather data from a bank of ACs, spread over a large area. Maximum number of working groups or nodes is considered as 16 and each group can have a maximum of 16 ACs so that overall total works out to a maximum

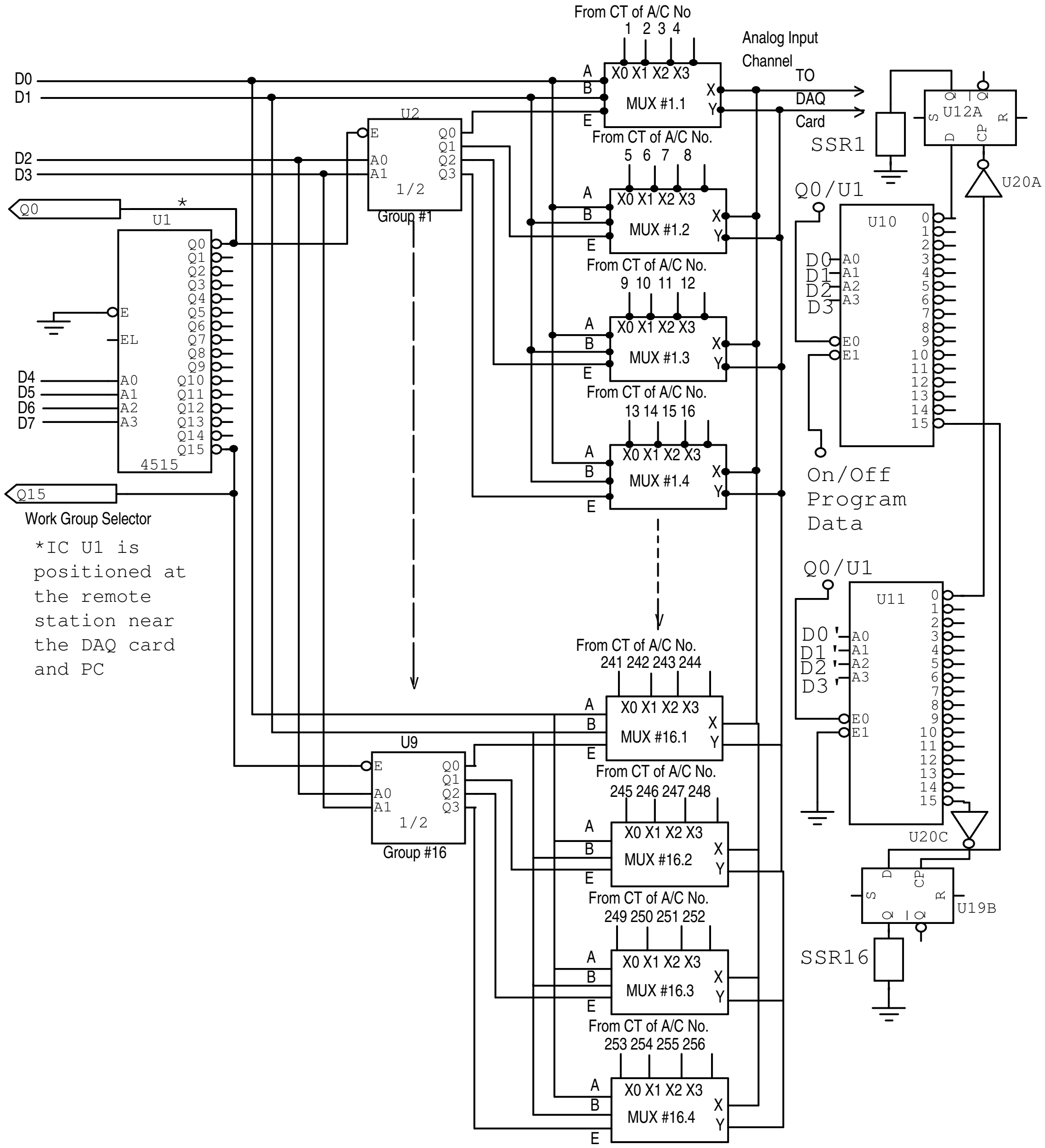

Fig. 3—Additional hardware for data acquisition

of 256, a sizable number. Let each of nodes be termed as node #1 to node #16 and be provided with a printed circuit board (Fig. 3).

However, IC marked U1 is excluded from PCB. Only this IC is positioned on a separate PCB at remote controlling station near PC. Incoming data lines $\mathbf{D_7}$ to $\mathbf{D_4}$ in this remote card are connected to DAQ card output. Depending on digital data present on data lines $\mathbf{D_7}$ to $\mathbf{D_4}$, only one work area is selected, because at any given instant of time only one of the Q_n outputs of IC U1 will be low. These same signal outputs Q_n are also used for selecting and controlling any AC. Remaining data lines ($\mathbf{D_3D_2D_1D_0}$) are routed from DAQ card to each of 16 PCBs in parallel. Similarly, outputs of multiplexers MUX1.1 to MUX 16.4 in 16 cards are all paralleled and brought to DAQ card. Locally at each work area, only one AC is monitored. Decoder and multiplexers on concerned PCB do this selection. Current transformers from all ACs within group are connected to analog multiplexer inputs, MUX1.1 to MUX 16.4. Thus, at any time, only one of the current transformers will be connected to analog input channel of DAQ card via multiplexer.

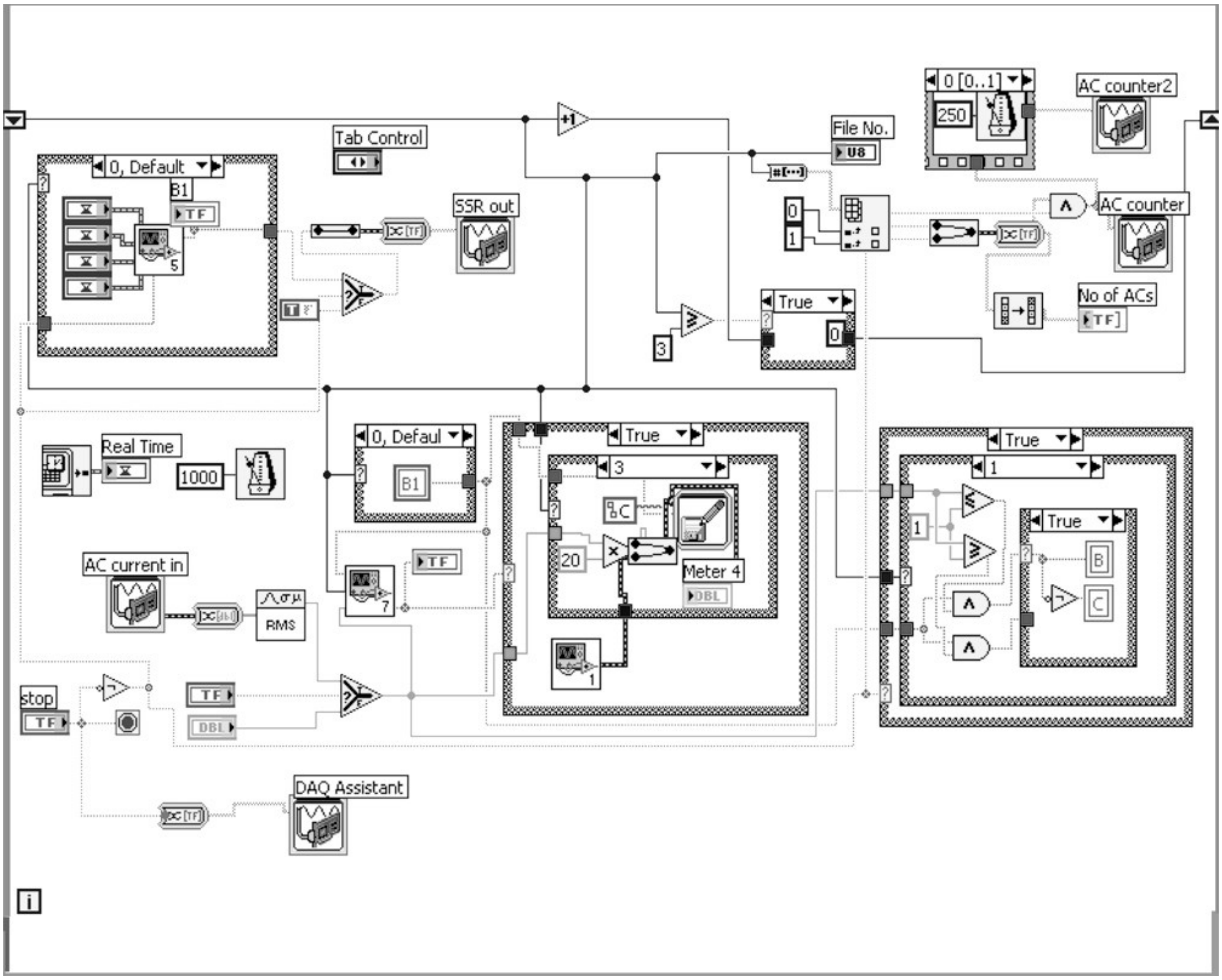

Fig. 4—Block diagram of virtual instrument

To illustrate functioning, consider VI outputs an 8 bit digital word, $\mathbf{D_7D_6D_5D_4D_3D_2D_1D_0}$ on a common data bus, connected to multiplexer circuit (Fig. 3). Then, four higher order bits $\mathbf{D_7D_6D_5D_4}$ define work group and lower order bits $\mathbf{D_3D_2D_1D_0}$ define specific AC within that group. For example, if $D_7D_6D_5D_4D_3D_2D_1D_0$ = 00001010, then line Q_0 of decoder U1 will be low and select work group number 1 [IC U2]. Since $\mathbf{D_3D_2}$ = 10, Q_2 of decoder U2 will be high and enable MUX #1.3. Last two bits $\mathbf{D_1D_0}$, which in this example are 10, select line X_2 i.e. CT connected to AC number #11 is connected to analog input channel of DAQ card. Rest of the logic is simple. VI successively generates address numbers 00000000 to 11111111 and places them on data bus so that all ACs are served in turn and data can be acquired from CTs of each AC. Data can then be processed as required.

Remote Control of ACs

ACs can be switched ON or OFF programmatically by developed VI, as per a predefined time schedule. If incoming electric supply fails, VI invokes a new set of conditions to override earlier ones and permits/inhibits operation of each AC system. For switching ON or OFF ACs, a demultiplexer and decoder arrangement can be used to set latches, which can drive SSRs into conduction.

For controlling one work area of 16 AC systems, IC 4555 has two sections, each having an inhibit signal pin. In one section, pin is grounded so that it works as a decoder, whereas other section functions as a demultiplexer. There are 16 such schemes, one for each work area. Enable pin EN of each section is connected together and gets its control input from Q_n outputs of work group selector IC U1, (Fig. 3). Thus, work area selection is same as that during monitoring. Demultiplexer

Table. 1—Extract of logged data

Date			Time			Current
Day	Month	Year	Hour	Minuts	Second	Ampere
2	2	2009	17	28	12	0.28*
3	2	2009	9	0	50	0.27*
3	2	2009	9	3	47	10.18
3	2	2009	9	53	15	0.29*
3	2	2009	10	12	12	10.04
3	2	2009	10	27	6	0.26*
3	2	2009	10	42	10	10.11
3	2	2009	10	54	31	0.29*
3	2	2009	11	12	35	10.15
3	2	2009	11	29	40	0.25*
3	2	2009	14	0	44	0.27*
3	2	2009	14	4	3	10.14
3	2	2009	14	58	11	0.25*
3	2	2009	15	12	48	10.13
3	2	2009	15	28	21	0.26*
3	2	2009	15	44	16	10.19
3	2	2009	15	2	8	0.21*
3	2	2009	15	15	59	10.2
3	2	2009	15	31	2	0.27*
3	2	2009	15	46	32	10.17
3	2	2009	15	54	5	0.23*
3	2	2009	15	11	24	10.22
3	2	2009	16	28	59	0.28*

*Values of current when only blower of AC is ON and compressor is OFF

receives its addresses from VI as digital data nibble $\mathbf{D_3D_2D_1D_0}$. Depending on data, a unique AC in work area is singled out to receive data. System takes into account prevailing conditions at any time and accordingly outputs data to switch ON an AC into operation if set parameters satisfy program requirements. These requirements are defined by two basic parameters; firstly, whether AC is authorized to receive standby power from a standby DG set during a power failure and secondly time zone, in which it is permitted to operate. $\mathbf{D_3D_2D_1D_0}$ signals to decoder section are delayed with respect to that for upper section, in order to satisfy timing requirements of D-Latch 4013. Delayed signals ensure that addressed D Latch stores data output by program, which addresses all ACs sequentially.

Results and Discussion

VI program, using LabVIEW 8.0 graphical programming language (Fig. 4), is stored in a PC provided with a backup UPS. Front panel also displays date and real time clock value in digital format and includes an analog type of ammeter to show current drawn. Control icons for each AC appear in a separate page so that their operational time slots can be easily entered. A provision is also built to permit or inhibit any AC to function on standby power.

Salient Features of Virtual Instrument (VI)

Developed VI has ease of installation, as very few additional components are required for building the set up. Any unskilled operator can be trained for using the system as control icons on desktop are user friendly and merely filling spaces provided for each parameter can enter control data. Basic control data consists of two time zones defined by two sets of start and end times in a 24 h period, with default values for each parameter. Front panel, which shows channel number being scanned and corresponding value of current on an ammeter, permits easy verification of progress of monitoring process. Status indication page is available to show current state of all ACs simultaneously. A diagnostic test switch is provided on front panel to check data logging operation. A sample test data can be entered from keyboard to verify whether same value is being correctly logged in Excel files. As data is in excel compatible format, off line processing can easily be undertaken to get additional information such as energy consumed, total expenditure incurred and performance data trends, which can indicate working condition of an AC. Program is designed in such a way that data logging occurs only when there is quantum change in current drawn by AC. This minimizes memory requirement. Overall installation cost, which is linked to total number of cables required, is significantly reduced because of hardware multiplexing at each work zone. Modular nature of software permits flexibility to add/modify system features. Integrated set up was tested for a limited number of ACs and found to be very satisfactory. Accuracy of current measured was calibrated against a standard ammeter. Recorded measurements were found to be within 1% of the true value. These observations were made on a split type AC unit (1.5 Tons).

VI can function very satisfactorily for monitoring ACs. Implementation cost depends upon length of cable routes. If routes are very long, TTL output command signals from DAQ card be increased suitably to compensate for voltage drop, if any, across cables that drive SSRs. This increase in TTL output may not, in most cases be necessary as SSRs, in general, function over a wide range of input control voltage, typically from 3-32 Volts DC. Analog signals from CTs can be boosted at each node by amplification to prevent loss of signal strength. Use of telephone cables can be explored to reduce cost. A short extract from an Excel file shows currents recorded (Table 1).

Conclusions

Virtual instrument using LabVIEW graphical programming language is a very effective way of monitoring and controlling AC systems. Even an unskilled operator can enter control parameters and retrieve gathered data in Excel compatible files, which are easily amenable for further analysis for energy management. Using a multiplexer and decoder arrangement have substantially reduced total cost of control cables. By resorting to this arrangement, only a single system is served at one time, thus reducing vulnerability to inter-signal interference.

Acknowledgements

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