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Full Length Research Paper

Automatic meter reading (AMR) based distribution security monitoring and distribution-supervisory control and data acquisition (D-SCADA) control

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Application of automatic meter reading (AMR) system is presently used for e-billing and e-monitoring. The power system of the future will incorporate advanced monitoring and control system that improve operations and system reliability. The concept presented in this paper includes installation of automatic meters in intermediate points of distribution system to monitor the load of the system and to control the enhancement function of the D-SCADA. The AMR modeling was designed and used for testing 11 KV practical distribution system of Mysore, Karnataka, India. The algorithm was designed for AMR based D-SCADA control for peak load and off peak load periods. MATLAB-Simulink and NI LabVIEW software is used for simulation.

Key words: Algorithm, network applications, output data, voltage regulation, load voltage.

INTRODUCTION

In today's competitive world, the power and energy sector of any country plays a major role in the growth of domestic, industrial, agricultural, telecommunication, education and public service sectors.

At present the Karnataka Power Transport Corporation Limited (KPTCL) is using the AMR in transmission side for the purpose of e-billing and e-monitoring. The SCADA security monitoring control system is also implemented in transmission sector through VSAT communication. But in the case of distribution in Karnataka region, automation is not currently used for security monitoring and control. Hence, it is suggested to install the automatic meters at intermediate points of distribution feeder. By this monitoring and control of distribution system is achieved by means of interfacing the AMR data into the D-SCADA system.

The AMR data of the 11 KV feeder at different locations can be transmitted through global system mobile (GSM) Rodney et al., 2007; Zheng, 2010) communication network to the distribution control centre. Then, these data can be interfaced with SCADA system, which controls the entire distribution system with reliable and secured operations and it also keeps away from the abnormal conditions. The AMR can measure the active, reactive and apparent powers of consumer load. It also measures the power factor, rms values of line and phase voltages, line and phase currents, with their angles respectively.Some of the open standard protocols for networking of energy meters like SNMP, MODBUS, DLMS/COSEM, TCP/IP etc.., are used and implemented in LabVIEW virtual instrumentation environment (Santosh and Jayaprakash, 2008). The Automatic Meter Reading and Control System (AMR) can read the both online and offline data logging and storage. These AMR's are widely used because of the cost effectiveness, security, load monitoring options, load curve monitoring and analysis, outage management (Sridharan and Schulz, 2001).

Supervisory control and data acquisition system or

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Abbreviations: AMR, Automatic meter recording; **D-SCADA,** distribution-supervisory control and data acquisition; **GSM,** global system mobile; **VSAT,** very small aperture terminal; **RTU,** remote terminal unit; **PLC,** programmable logic controllers; **IED,** intelligent electronic devices; **VR,** voltage regulation; **PMU,** phasor measuring unit.

SCADA refers to the combination of telemetry and data acquisition (www.abb.com/networkmanagement). SCADA includes the collecting of the information via a RTU (remote terminal unit), PLCs (programmable logic controllers) and IEDs (intelligent electronic devices), transferring it back to the central site, carrying out any necessary analysis and control and then displaying that information on a number of operator screens or displays.Three of the most important parts of a SCADA system is master station, remote terminal (RTU, PLC, IED) and the communication between them.

DSCADA (Ha et al., 2009) is a set of technologies for providing remote monitoring and control of equipment located in distribution substations and out on the distribution feeders themselves. SCADA is a basic building block upon which smart distribution is based. DSCADA provides the ability to monitor the distribution system components in real-time. Smart distribution applications use the monitoring and control capabilities provided by DSCADA to determine steps needed to optimize the performance of the distribution system. The main purpose of the DSCADA system is to continuously monitor the loading, status, and performance of equipment located on distribution feeders. Under normal conditions, the system periodically acquires real-time values of current and voltage at various strategic measurement points and the open/closed status of all monitored switches (Lee and Shin, 2009).

This paper includes advanced AMR along with the synchronised phasor measuring unit (PMU) block (Narendra and Weekes, 2008).. Hence it is used to measure the magnitude and phase angle of the voltage and currents directly from the PMU and this can be further used for study of state of the system security monitoring and control. The applications of PMU are synchrophasor capability in motor protection, AGC / SIPS analysis, capacitor bank performance, analysis of load shedding schemes, distance relay performance during small disturbances etc (Mark et al., 2007). The AMR modeling was designed which measures all the output values of electrical quantities at different buses of distribution system (Appendix 2). The algorithm was designed for AMR based distribution security monitoring and D-SCADA control. During the peak load and off peak load periods, the voltage drop problems in distribution systems are considered and these can be monitored by AMR and the system can be controlled by D-SCADA through capacitor switching. The objective is to control the system from security violations through the proposed algorithm.

A test environment is implemented and the results are obtained for 11 KV practical distribution system of Mysore city, Karnataka, India. MATLAB-sim power system tool box is used for the simulation of AMR design and load flow calculations has been performed for the test system and the algorithm was programmed and simulated in NI LabVIEW software effectively.

SYSTEM UNDER TEST

The infrastructure of power system distribution network of Mysore, Karnataka was tested for 11 KV distribution network of the Chamundipuram sub division Industrial feeder 11D6. The case study of the system was simulated in Matlab simulink sim power system.

Figure 1 shows the single line diagram of the Chamundipuram sub division industrial feeder 11D6, distribution network of Mysore city. The total capacity of the feeder is 6339 KVA and it consists of 34 distribution transformers (11KV/440V), 11 HT consumers 1.78 MW and the 34 LT consumers 4.57 MW of connected load. This feeder comes under 66/11 KV south master unit sub station (MUSS), more details are shown in the Appendix 1. Thermal loading is considered based on standard conductors like coyote, rabbit, weasel etc.

SYSTEM DESCRIPTION

D-SCADA functions

D-SCADA offers the following major functions;

(a) SCADA, real-time monitoring and control.
(b) Advanced network applications including network modeling.
(c) Outage management including crew and resource management.
(d) Work management.

SCADA, real-time monitoring and control offers full SCADA functionality including data acquisition, device and sequence control, alarms, events management and geographic world maps etc. Advanced network applications provide the major functions such as, network state estimation (real time load calibration), load flow calculations, short circuit calculations, optimal feeder reconfiguration, loss minimization (MVAR control), load management, feeder voltage control, load switching tracing and dynamic line coloring, fault location, isolation and system restoration and automatic switching plan generation. The outage management functions are trouble call entry and management, manual or automated call service, feed back to customers, fault localization/inference engines, restoration prioritization and follow-up, outage reporting, outage statistics and indices, outage causes and equipment faults, customer outage notification and history. Crew and resource management functions include scheduling (time and capabilities), crew tracking (GPS tracking), dispatching and assignment, optimal route planning, follow-up and reports and mobile crew data communication. Work management includes tagging and clearances, insertion of jumpers and generators, insertion of temporary line cuts and grounding switches, operation step planning including reversal (back out) function, validation simulation scheduling, distribution of work orders, execution and follow-up.

AMR design

The advanced AMR includes the phasor measuring unit (PMU) block. The vital use of AMR is to provide the data of magnitude of phase and line voltage, phase and line current and their angles in degrees. It also measures the KW, KVA, KVAR, PF etc. The same data is used for analysis of energy losses in distribution system. Figure 2 shows the AMR measurements. It consists of AMR model

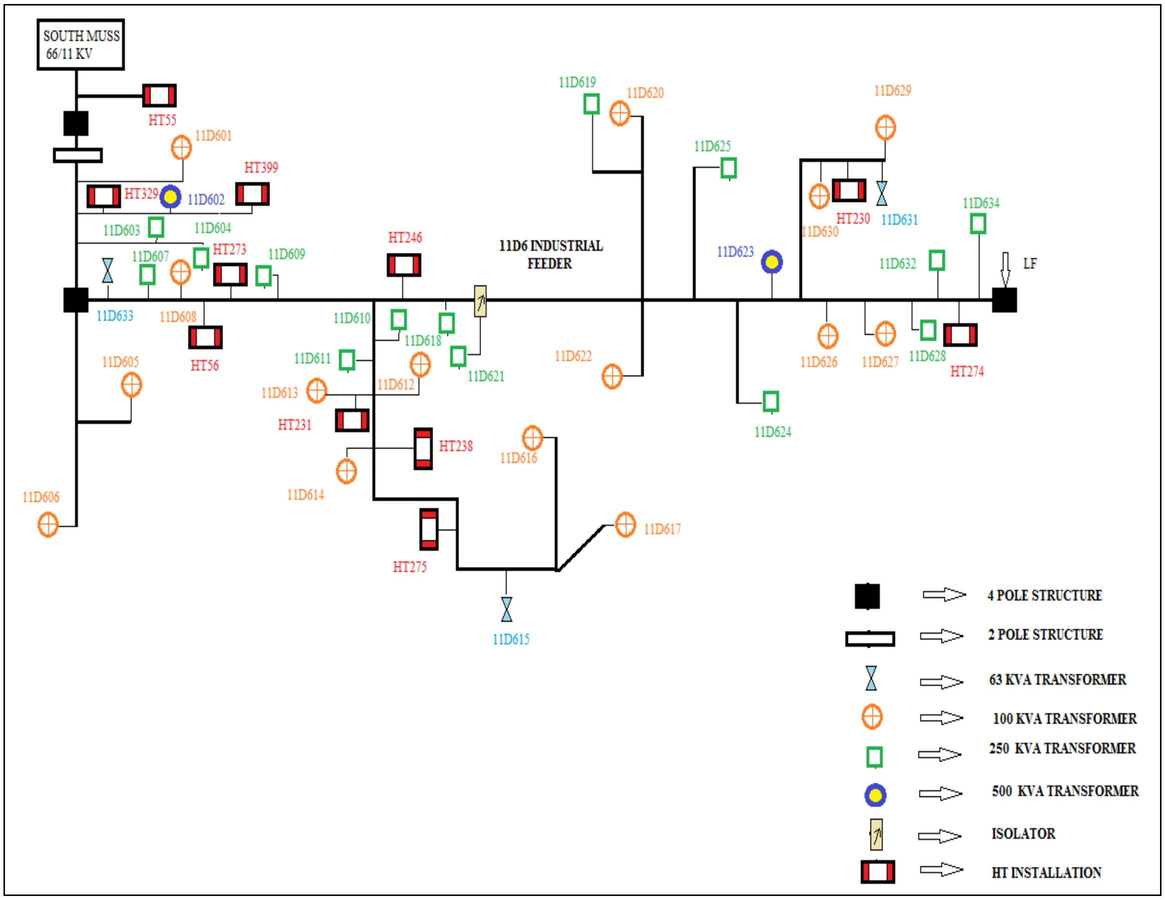

Figure 1. Single line diagram of the Chamundipuram sub division Industrial feeder 11D6, distribution network of Mysore city.

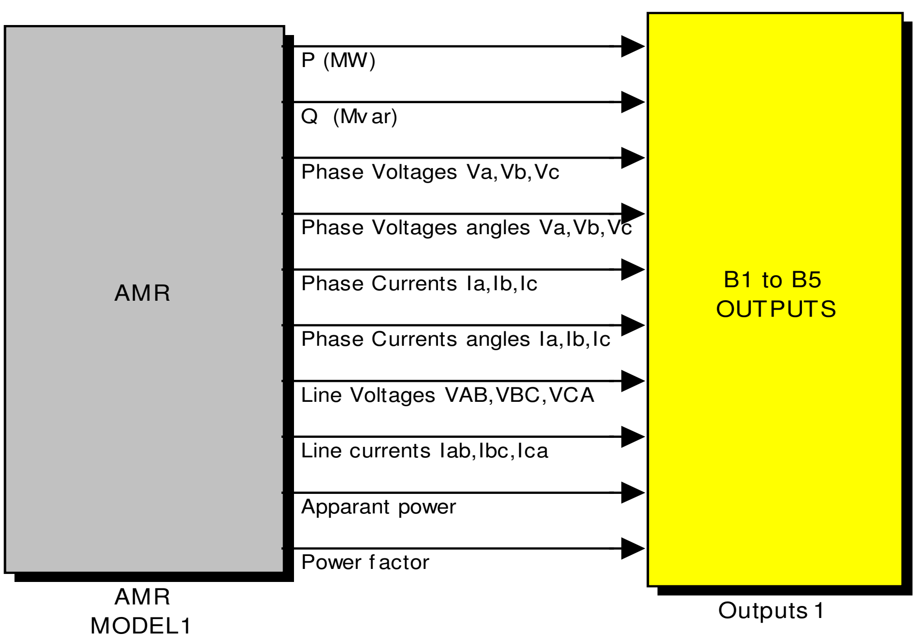

Figure 2. AMR Measurements.

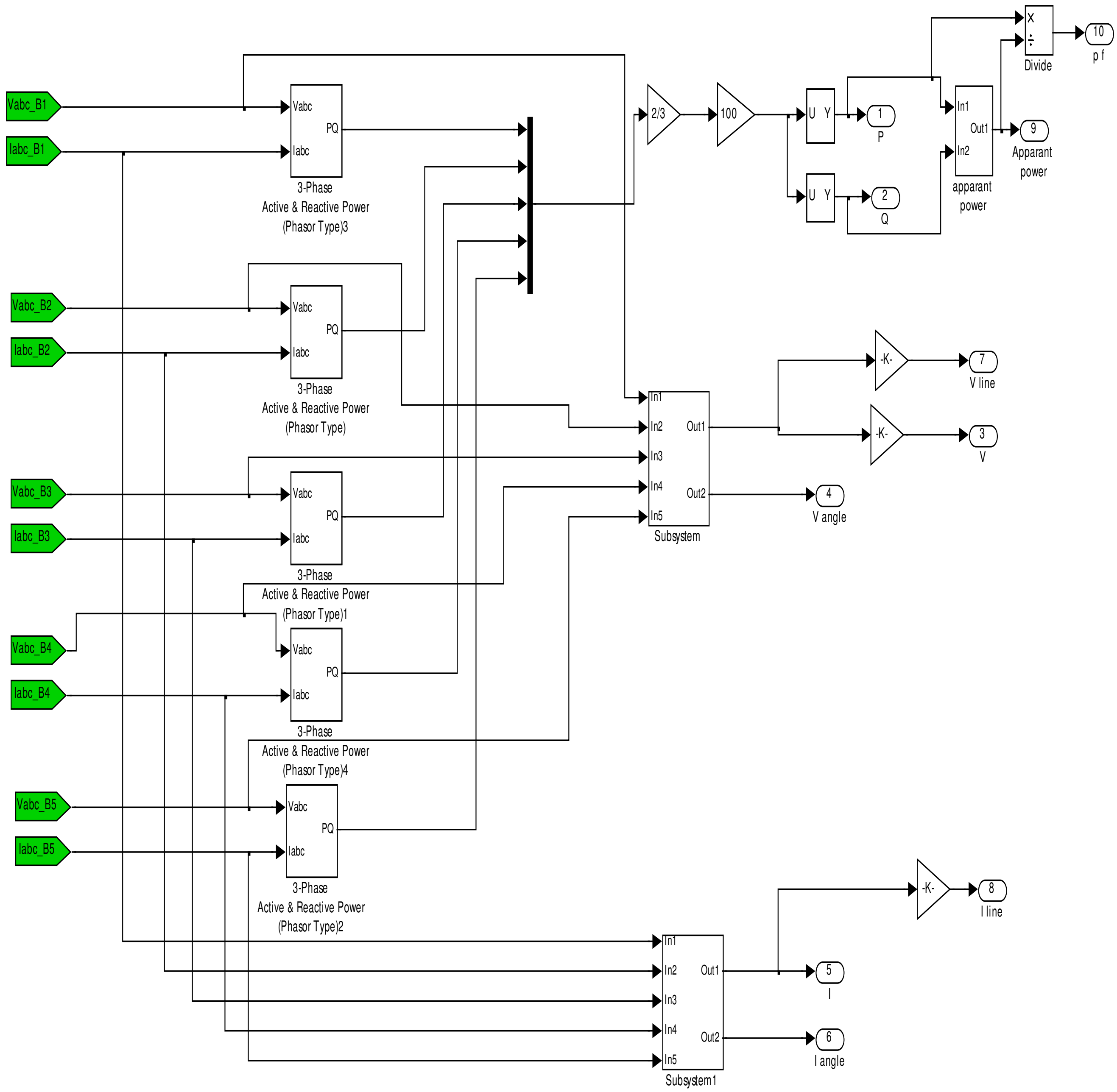

Figure 3. AMR Simulink model.

and output display block. It measures the values of the above mentioned parameters of buses 1 to 5. Automatic meters are connected to the monitoring and control centre through suitable communication (GSM) equipment.

This powerful AMR system is designed to support interfacing to the D-SCADA. By taking the values of phase to ground (per unit) voltage V_{abc} and current I_{abc} at individual busses of three phase 11 KV distribution line, a three phase active and reactive power measurement block of phasor type. which receives the three phase bus voltages V_{abc} and currents I_{abc} and calculate the active power (P) and reactive power (Q) values. Converting the obtained per unit values of P and Q in to the base values and connecting the ports to the output terminals 1 and 2. The phase and line voltages can be directly read from received signals V_{abc} and I_{abc} and then convert them into per unit to base values and calculate line and phase voltages and currents.

The V_{abc} and I_{abc} are in complex form, hence it must be converted into polar form using complex to magnitude/angle conversion block. The obtained angles of respective voltage and current values are in radians and then converted into degrees. Apparent power and power factor can be calculated by using obtained values of P and Q.

Figure 3 shows the model of AMR, consisting of five units- each unit measuring the data of five busses. The output ports of the AMR are connected to the output blocks consisting the display blocks and scopes to read the output data. Figure 4 shows the PMU

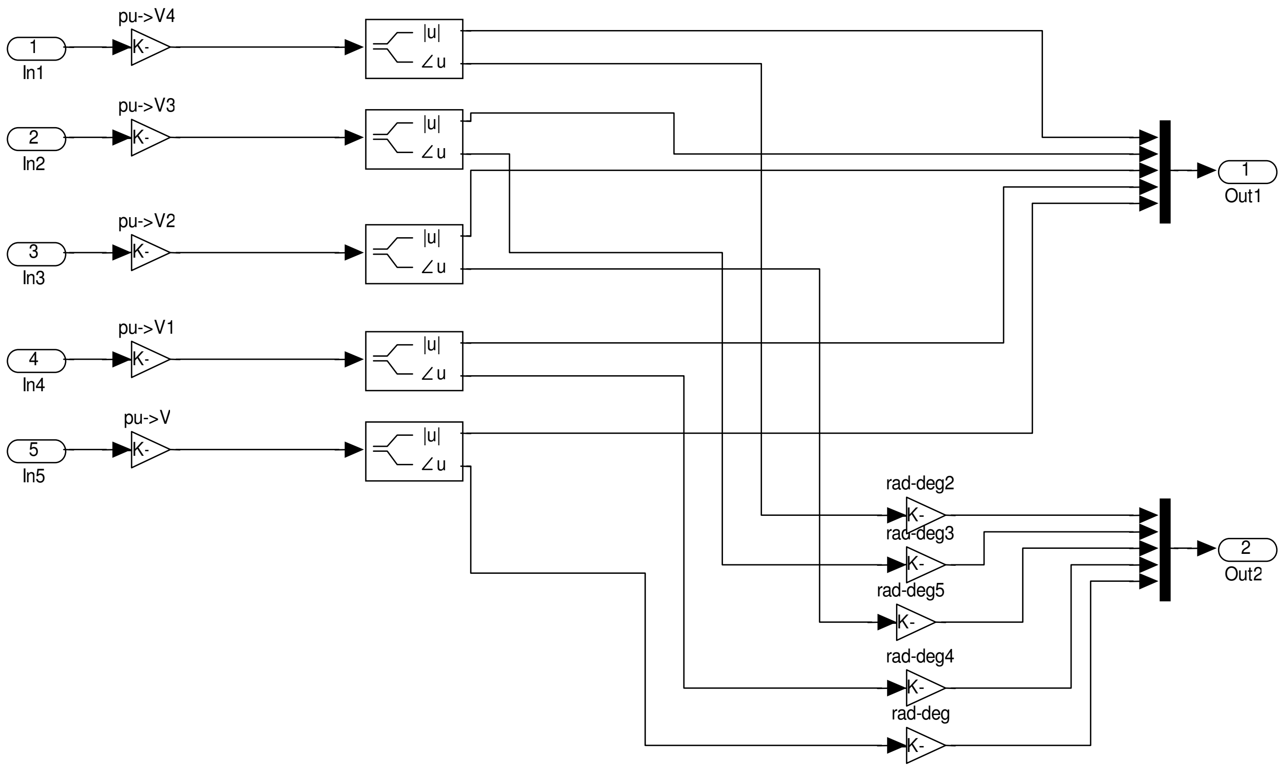

Figure 4. PMU Simulink model.

simulink model and which consists of voltage /current and with their angle measurement block.

Mathematical equations used for AMR modeling are:

1. Active power (P) : $\sqrt{3}\ V_L\ I_L\ \text{Cos}\ \phi$
2. Reactive power (Q) : $\sqrt{3}\ V_L\ I_L\ \text{Sin}\ \phi$
3. Apparent Power (S) : $\sqrt{3}\ V_L\ I_L$ or $\sqrt{(P^2 + Q^2)}$
4. Power factor (pf) : $\frac{\text{Apparent power (P)}}{\text{Active power (S)}}$
5. Voltage Regulation (VR):

$$\%VR = \frac{\text{No load Voltage } V_0 - \text{On load Voltage } V_L}{\text{On load Voltage } V_L} \times 100$$

PROPOSED ALGORITHM

Here the development procedure of methodology is illustrated. The overall concept has been represented in Figure 5. It gives the algorithm for AMR based distribution security monitoring and D-SCADA Control. In this algorithm the focus is on two security violations - one is peak load period usually from 6 to 10 PM and the other is off peak load period during night between 10 PM and 6 in the morning. During peak load period, the voltage at the far end will be reduced and the voltage regulation is poor. Hence to improve the voltage profile and voltage regulation at far end, auto switching of the capacitor banks are necessary in the distribution line (Ellithy et al., 2008). This will improve the voltage profile, voltage regulation at the far end, minimizing the losses and balancing the load. The algorithm is as follows:

Step 1: Read the system data and close all the tie switches and perform the power flow.

Step 2: If the system is under normal condition, display the green light, else display red light and give signal to the alarms and buzzers.

Step 3: If the system has any abnormalities then violation of the security constraints like V and I, exceeding or limiting values will be determined by the smart meter output data.

Step 4: List out the number of security violations and send the priority signal.

Step 5: The received priority signal is checked for the type of security violations, and then calculate the voltage regulation.

Step 6: Condition checking is done for the voltage regulation (VR) in acceptable limits (0 to 5%). If the limits are crossed, then the security violations are described as two ways. One is peak load period (VR ≥ 5%) and another is off peak load period (VR ≤ 0%).

Step 7: The capacitor bank has to be switched on for peak load and switched off for off peak load automatically.

Step 8: Run the power flow and repeat the step 5 to 6 until the VR is in acceptable limits (0 to 5%). Then the program has to realize the system to be under normal condition and it must indicate the green light signal, then the program has to be terminated.

Figure 6 shows the process flow diagram of the overall simulation part. The MATLAB output can be manually entered into the LabVIEW to simulate the proposed algorithm.

RESULTS AND DISCUSSION

The MATLAB simulation results of the test system shows

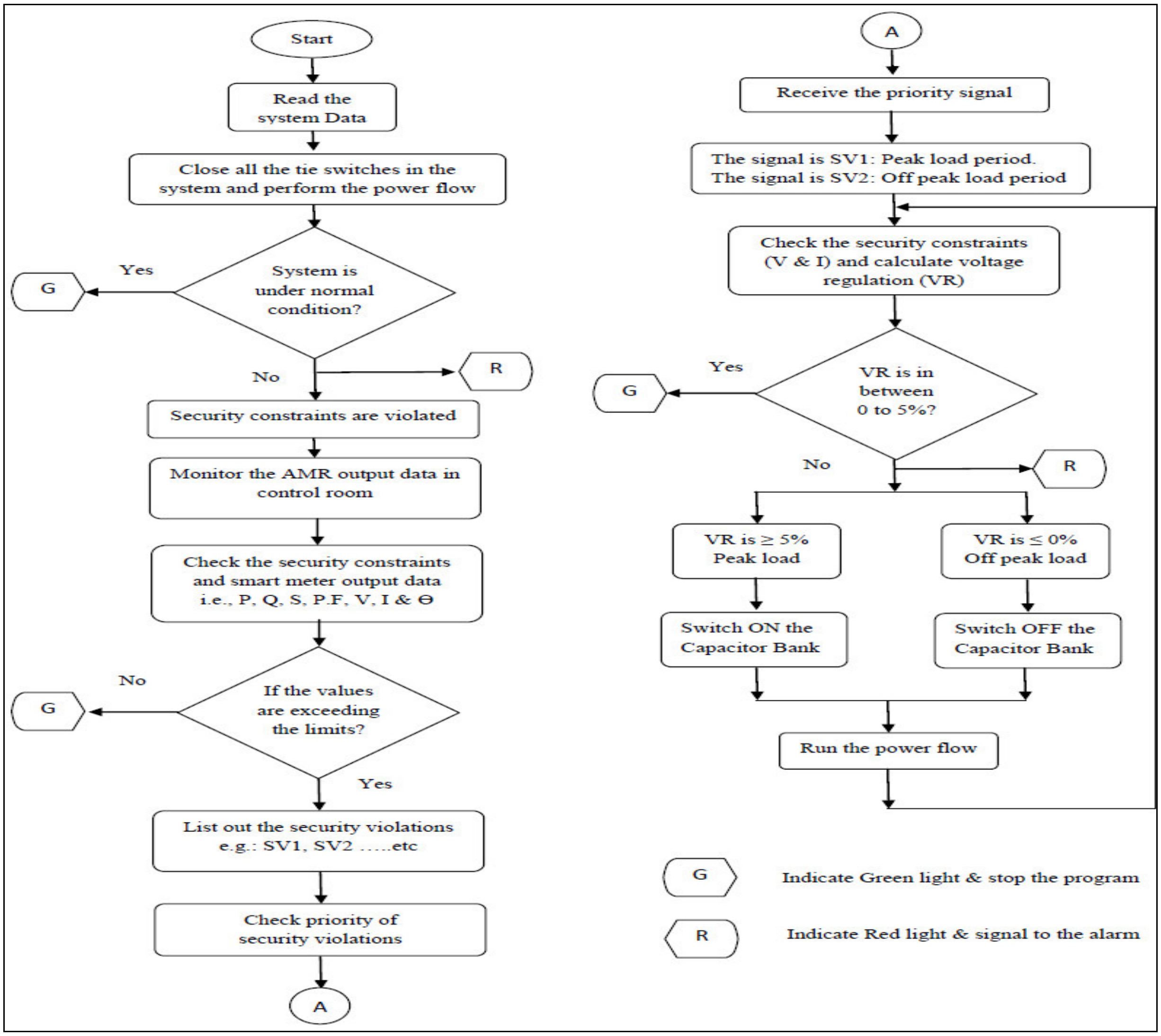

Figure 5. AMR based distribution security monitoring and D-SCADA control algorithm.

the AMR measurements for different cases in Appendix 2. These results are manually entered as an input to the LabVIEW and algorithm was simulated and the security monitoring and control can be achieved by displaying red and green indication during peak and off peak load periods respectively.

Case 1: It refers to the system to be under normal load condition, the voltage drop at the far end due to normal loading within the acceptable limit. Hence the green light is indicated in the control room according to the algorithm.

Case 2: It refers to the system to be under peak load condition, the voltage drop at the far end due to peak loading exceeding the acceptable limit. Hence the red light is indicated in the control room according to the algorithm. And also it sends the signal to the capacitor bank to switch on its position helping to improve the voltage profile at the far end.

A sudden fall in peak load, when the capacitor is connected in the line causes and increase in the value of the voltage above the limits, harming the insulation of the cables, machines etc. Hence it is devised to switch off the capacitor bank as shown in algorithm. These results can be analysed from Table 1 showing the calculated values of power consumption of the load, no load voltage V_0, on load voltage V_L, voltage regulation VR, size of capacitor bank in KVAR and power factor.

Figures 7 and 8 shows the simulation of AMR based distribution security monitoring and D-SCADA control algorithm respectively in LabVIEW software.

The online monitoring display includes the load switches,

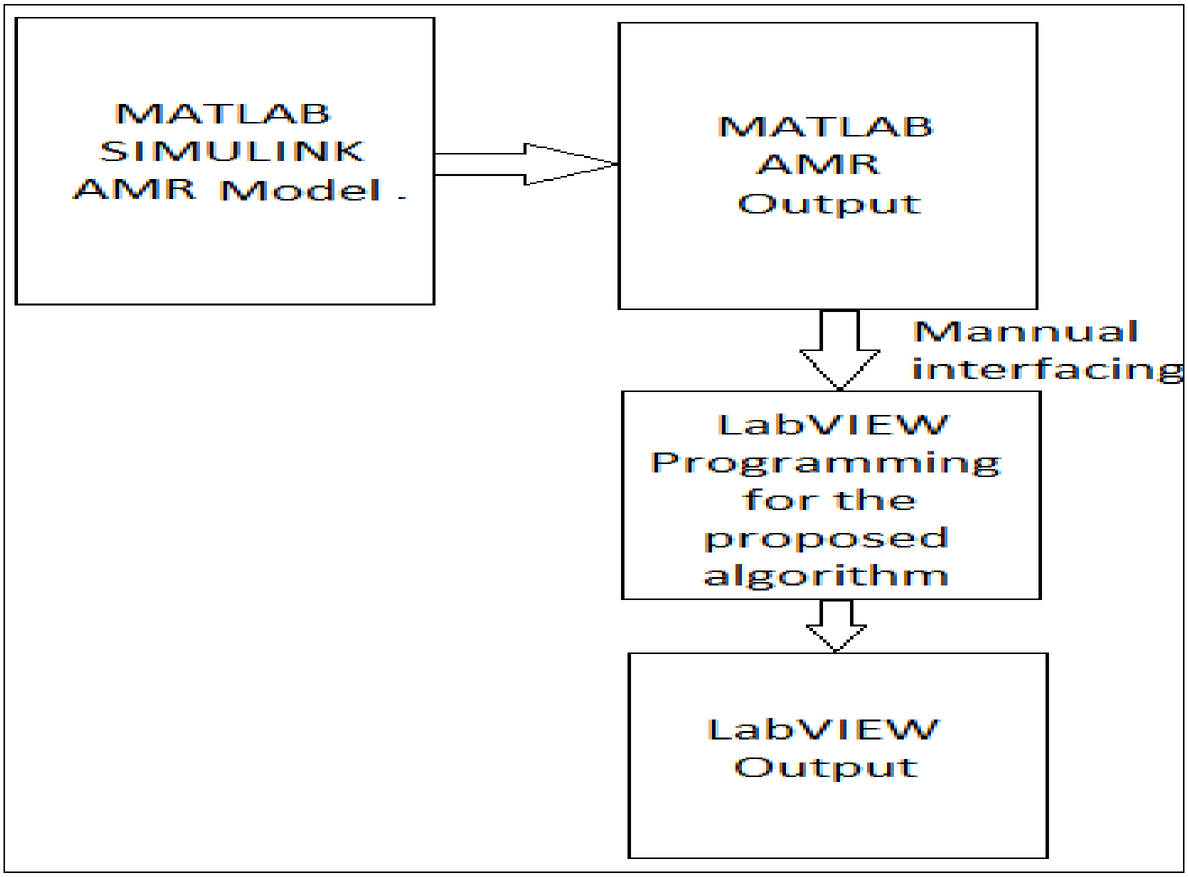

Figure 6. Process flow diagram.

Table 1. Test system result analysis.

S. No	Condition	Load (MW)	V_0 (KV)	V_L (KV)	VR (%)	C (KVAR)	P.F	Status of the system and control action
1	Normal	5.346	11	10.54	4.18	----	0.904	System is stable
2	Peak load	9.591	11	10.31	6.27	----	0.901	Switch ON the CB
3	Peak load	9.191	11	10.51	4.45	800	0.995	Voltage and VR is improved
4	Fall in peak load	5.659	11	10.86	1.27	800	1	Switch OFF the CB
5	Back to normal	5.346	11	10.54	4.18	----	0.904	System is stable

indicators, measurements and load curve, status capacitor bank switching etc. In Figure 8 red light indicates that the system is under peak load condition.

Conclusion

This paper illustrates an algorithm for AMR based distribution security monitoring and D-SCADA control. This technique is one of the most reliable and easily applicable in distribution systems. The utilization of AMR is the advanced technology for accurate measurements and theft control and is very helpful to achieve the objective in security operation of the power system. The test system is simulated in the MATLAB 7.8 version / SIMULINK and LabVIEW effectively. This AMR also containing PMU which directly measures the angles of the voltage and currents will be helpful to implement for and security monitoring and control of D-SCADA system.

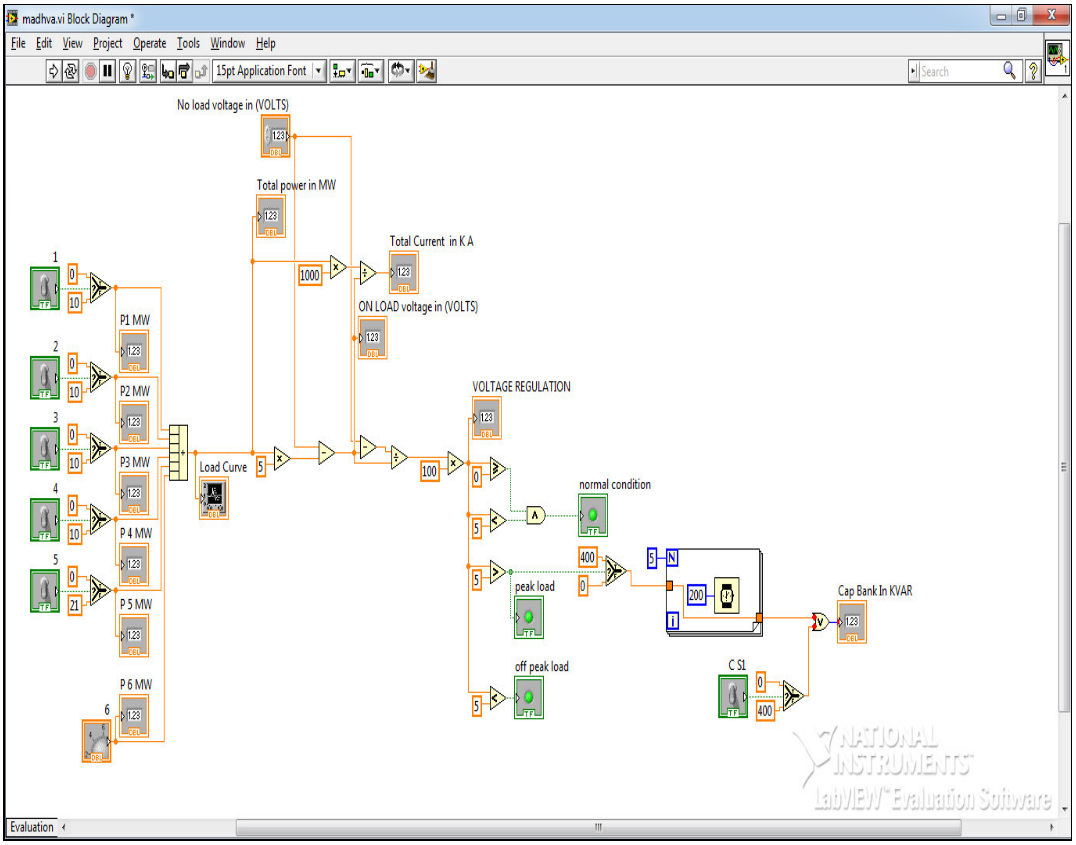

Figure 7. Programming diagram for proposed algoritham in LabVIEW.

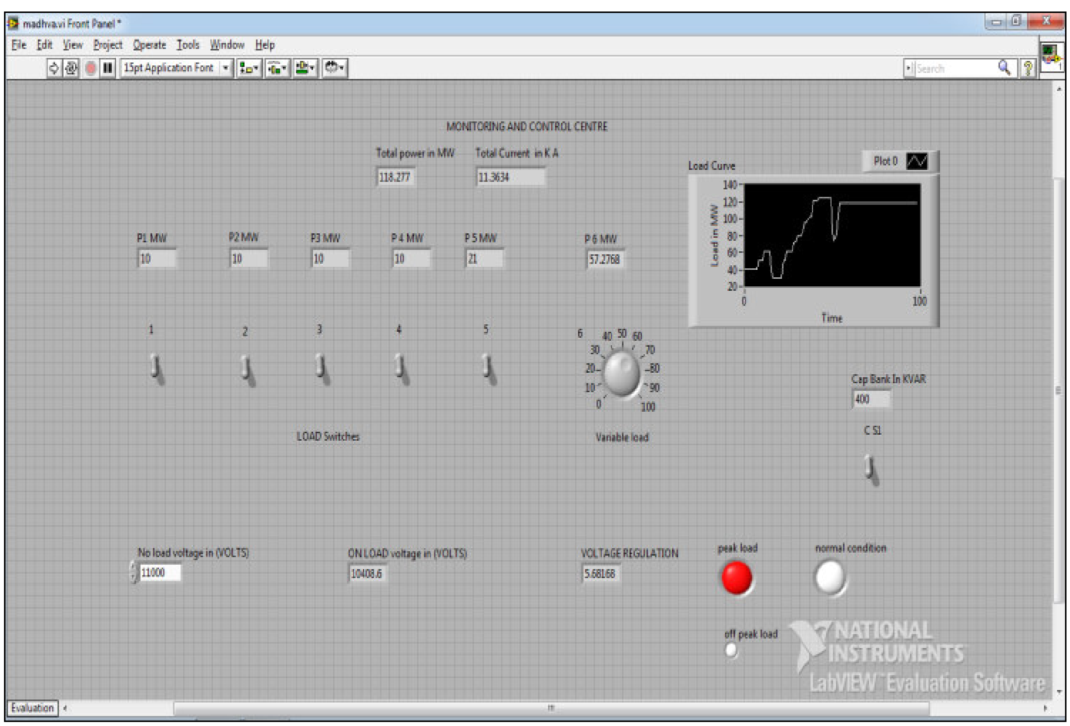

Figure 8. Results obtained from LabVIEW.

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APPENDIX 1

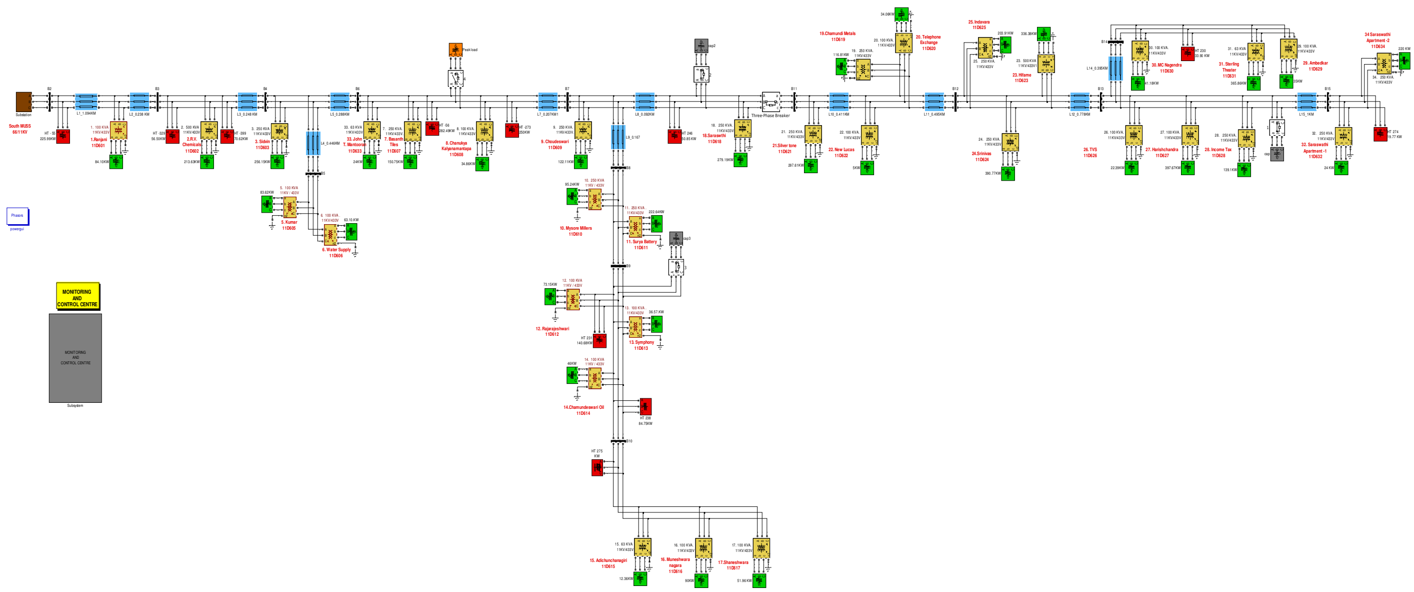

Figure 1. Distribution system network of Mysore City, Karnataka, India. Chamundipuram sub division industrial feeder 11d6, MATLAB simulink test system model.

Table 1. Load data details of distribution transformer center substation.

S. No.	Location of Transformer	DTC code	Capacity [KVA]	Connected load		
				KW	HP	Total load [KW]
1	Ranjani	11D601	100	11.38	97.48	84.10
2	R .V. Chemicals	11D602	500	84.09	173.64	213.63
3	Sidwin	11D603	250	27.95	305.92	256.15
4	Chamundi feeds	11D604	250	14.68	65.25	63.35
5	Kumar	11D605	100	12	96	83.62
6	Water Supply	11D606	100	3.42	8	9.388
7	Basanth tiles	11D607	250	32.06	159.11	150.75
8	Chanukya Choultry	11D608	100	30.38	6	34.86
9	Choudeshwari	11D609	250	21.79	134.49	122.11
10	Mysore millers	11D610	250	6.28	119.25	95.24
11	Surya battery	11D611	250	14.47	281.4	222.64
12	Rajrajeshwari	11D612	100	1	96.75	73.15
13	Symphony	11D613	100	3	45	36.57
14	Chamundeshwari	11D614	100	1.24	60	46
15	Adichuncnchanagiri	11D615	63	12.36	0	12.36
16	Muneshwara nagara	11D616	100	76.2	18.5	90
17	Shaneshwara	11D617	250	51.96	0	51.96
18	Saraswathi	11D618	250	61.99	291.95	279.19
19	Chamundi metals	11D619	250	8.58	145.09	116.81
20	Telephone exchange	11D620	100	34.06	0	34.06
21	Silver tone	11D621	250	38.4	346.82	297.61
22	New lucas	11D622	100	5	0	5
23	Hifame	11D623	500	45.75	389.57	336.38
24	Srinivas	11D624	250	341.53	66	390.77

Table 1. Cont.

25	Indavara	11D625	250	42.7	216.07	203.89
26	TVS	11D626	100	0	30.02	22.39
27	Harishchandra	11D627	100	175.79	297.41	397.67
28	Income tax	11D628	250	139.1	0	139.10
29	Ambedkar	11D629	100	35	0	35
30	MC Nagendra	11D630	100	41.18	0	41.18
31	Sterling theater	11D631	63	332.24	45	365.86
32	Saraswathi apartment 1	11D632	250	24	0	24
33	John T. Manthooran	11D633	63	16	0	16
34	Saraswathi apartment 2	11D634	250	220	0	220
	Total	11D6	6339	1965.58	3494.72	4570.788

Table 2. HT load details of the feeder 11D6.

S. No.	R .R. No	KVA	KW
1	HT246	90	50.85
2	HT329	100	56.50
3	HT273	250	141.24
4	HT231	249	140.68
5	HT238	150	84.75
6	HT230	60	33.90
7	HT275	1200	677.97
8	HT55	400	225.99
9	HT56	500	282.49
10	HT399	125	70.62
11	HT274	35	19.77
Total		3159.50	1784.76

Table 3. Industrial feeder (11D6) conductors and line length details.

Length of overhead line distribution		**9.313 KM**
Distribution	Type of conductor	Length [km]
3 wire	Coyote	2.889
3 wire	Rabbit	6.087
3 wire	Weasel	0.338
Length of underground cable		0.214KM
Type of conductor	Diameter	Length [km]
UG	3.95 mt	0.241
Length of trunk line (mt)		2849
No. of tapping lines		28
Tapping lines (mt)		6705

Tapping	Length	Tapping	Length	Tapping	Length
1	234	11	34	21	12
2	424	12	14	22	2
3	8	13	338	23	329
4	94	14	3672	24	31
5	21	15	25	25	4
6	190	16	24	26	53

Table 3. Contd.

7	87	17	98	27	20
8	384	18	297	28	43
9	22	19	176		
10	13	20	58		

APPENDIX 2

Results

Case 1: Under normal condition

Total load = 5.346 MW, No load Voltage = 11 KV, Line Voltage at end point = 10.54 KV, Voltage regulation = 4.18%

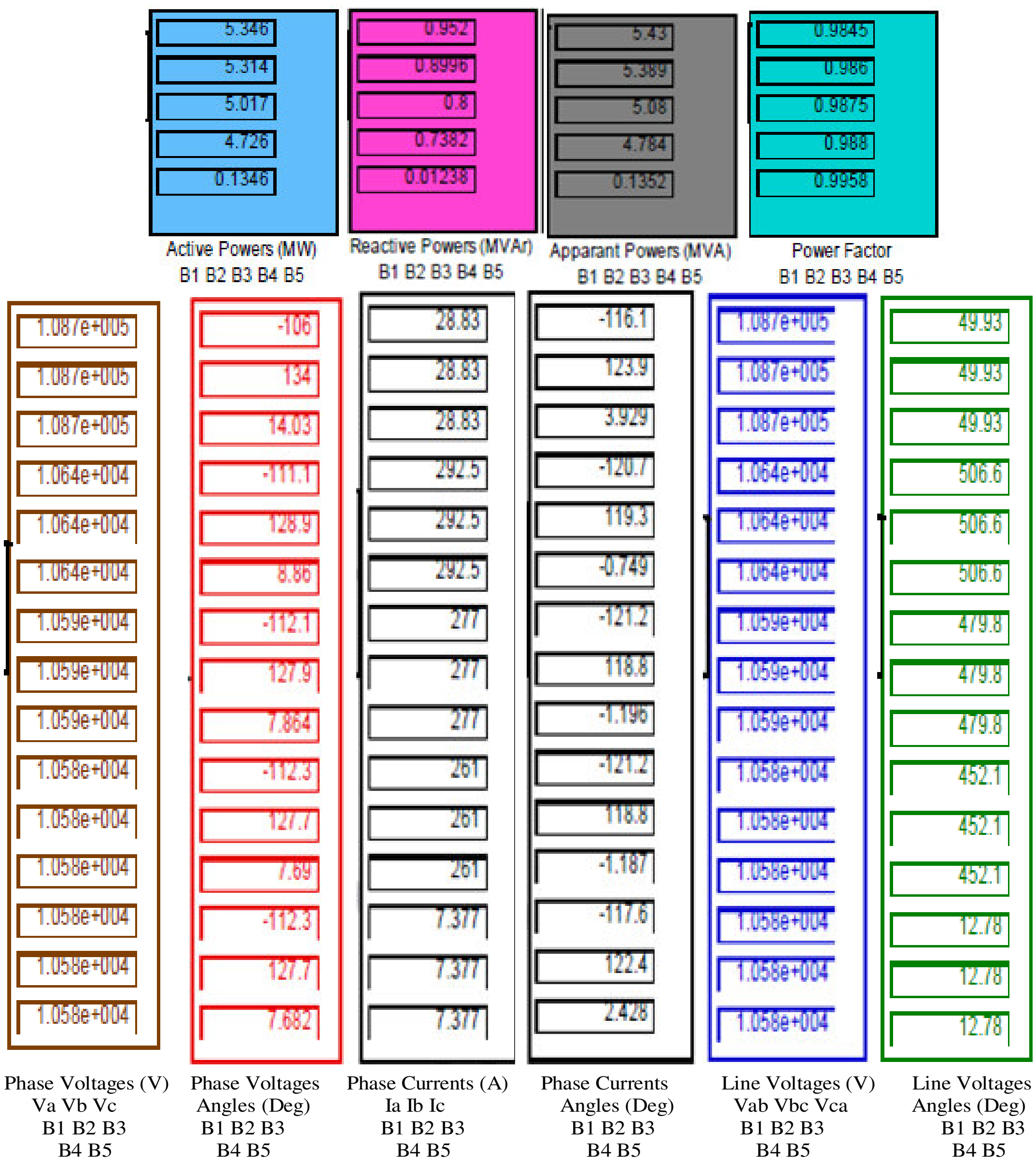

Figure 1. AMR output data of buses 1 to 5 of case 1.

Case 2: Under the peak load condition

Total load = 9.591 MW, No load voltage = 11 KV, Line voltage at end point = 10.31 KV, Voltage regulation = 6.27%.

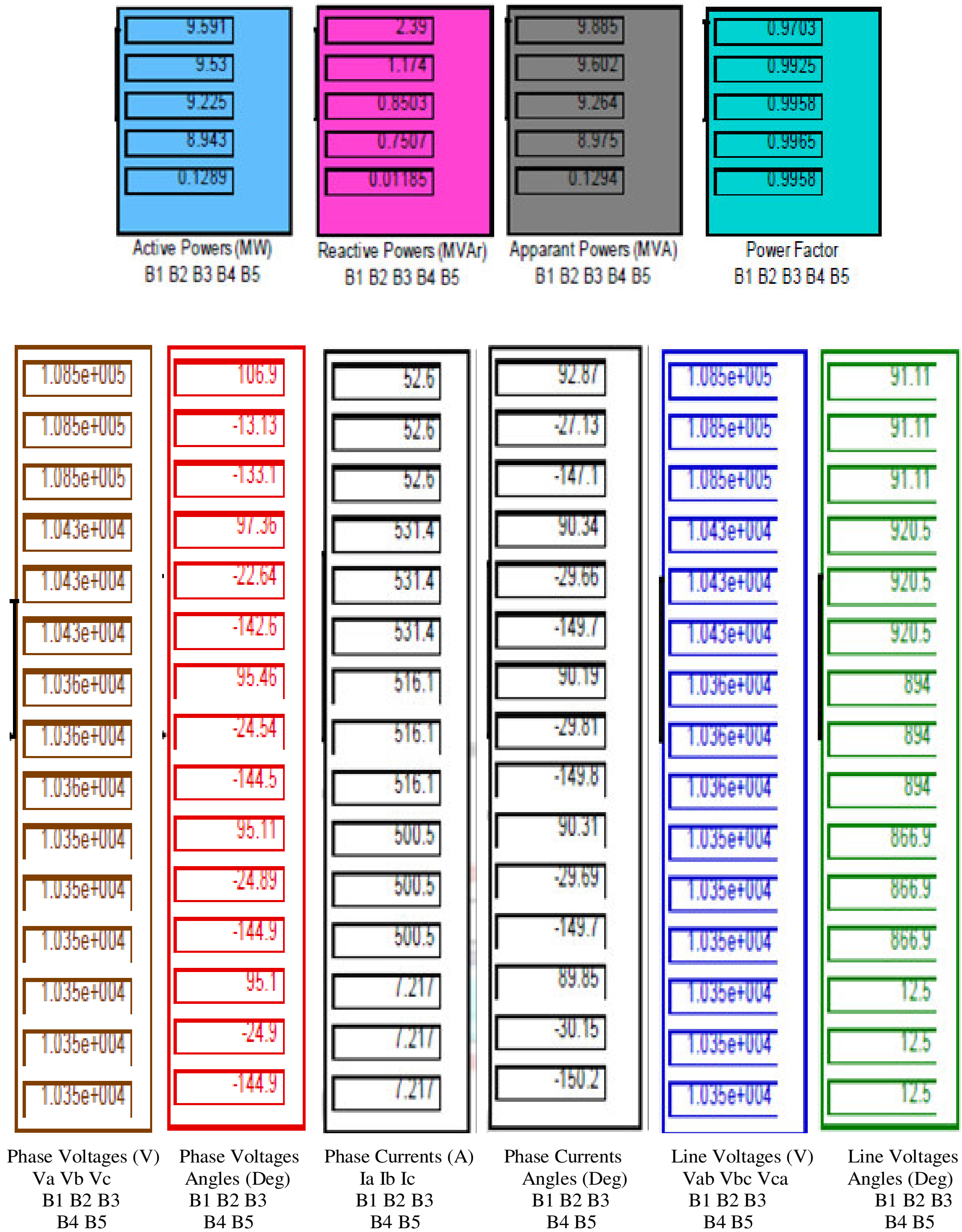

Figure 2. AMR output data of buses 1 to 5 of case 2.