DEVELOPMENT OF HIGH PERFORMANCE AUTOMATIC VOLTAGE STABLIZER FOR TELECOMMUNICATION APPLICATIONS

A dissertation submitted to the
Department of Electrical Engineering, University of Moratuwa
in partial fulfillment of the requirements for the
Degree of Master of Science
by:

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December 2008

DECLARATION

I certify that the work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

UOM Verified Signature

S.S.K. Thotagamuwage

22-12-2008

I endorse the declaration by the candidate.

DR J.P. Karunadasa

Supervisor

ABSTRACT

The Telecommunication industry in Sri Lanka is having very fast growing and expanding services to their customers. Also, the increasing number of telecom service providers has entered to the industry during past decades, with much competitive Tariffs. At the same time, a regulatory body called "Telecommunications Regulatory Commission of Sri Lanka" (TRCSL) was legally formed under the Sri Lanka Telecommunication (Amendment) Act No. 27 of 1996 and start benefiting to the nation in terms of quality, choice and value for money by extending the optimum conditions of the telecommunications industry in Sri Lanka.

The main challenge of the service provider is to sustain with the competitive Tariff reductions and advancement of their services to customer door step demanding by the industry. Not like in other industry, the telecom customer is having the freedom to select any service provider by own decision without facing any monopoly or other influence by the industry. This automatically creates the industry to reduce their OPEX & CAPEX continually. The CAPEX is always increasing and the reduction possibility exists only with OPEX in the telecom industry.

Electricity is contributes to the major portion of OPEX of remote telecom site operations. The electricity by means of Diesel Generator (DG) operation or Commercial supply (CEB/ LECO) is always a difficult facility in remotely operated telecommunication base stations. This is due to the nature of the location of the selected site and the quality of the nearest/ rural commercial supply. Due to this, the site needs to run with the DG in most of the time period of the day or face with service outages due to interruptions of the electricity with huge OPEX and unexpected losses in income.

The main objective of this research project is to develop a system for automatic voltage regulation at remote telecommunication sites with customized features. The unit is expected to operate under extreme climate,

environmental & power abnormality conditions to regulate & maintain reliable & accurate sinusoidal voltage profile to the sensitive telecommunication equipments. In addition, the development of the unit should capable to meet the protection requirements from various environmental & power abnormalities, modular construction for easy customization at initial site installations & maintenance, Increased system efficiency, output power quality, fast voltage correction, long life of operation, noise free regulation, less maintenance attention, automatic monitoring, controlling & operation, relatively small construction with lightweight package at lowest possible cost will also be some of the expected outcomes of this development.

This research paper will present the background review, detail technical analysis, theoretical development & design, financial analysis and possible areas of further improvements. At the same time, sample implementation also carried out in several sites of Lanka Bell Ltd was proved a considerable financial benefit back to the company.

The outcomes of this research will be a remarkable development in the telecom industry. We also supposed to share this knowledge with all the interesting parties to extend the benefits not only to the telecom service providers, but also to the customers by means of lowest tariffs.

CONTENT

ACKNOWLEDGEMENT

I would like to thanks my supervisor, Dr J.P. Karunadasa, Head of Electrical Engineering department, for his right direction, great insights, perspectives, guidance and sense of humor. My sincere thanks go to the former Head of Electrical Engineering department Professor H.Y.R. Perera, course coordinator, Dr. Lanka Udawatta and all the academic staff who helped in various ways to clarify the things related to my academic works in time with excellent cooperation and guidance. Sincere gratitude is also extended to the people who serve in the Department of Electrical Engineering.

I also thanks to Mr. Krishan Gamage, General Manager, Technical Operations, Lanka Bell Limited for arranging the required funding for the research implementations, Mr. Kusal Saranath, Divisional Manager, Technical Operations, who gave special guidance on clarifying technical matters and, Anura Liyanage (Engineer, Maintenance) for his time on helping me to conduct the preliminary technical surveys and gathering technical literatures in many of the sites in various places in Sri Lanka.

I also like to thank my wife, Inoka for her time & kind effort to re-check the draft copy of the Thesis to make this a perfect presentation.

Lastly, I should thanks many individuals & friends who have not been mentioned here personally in making this educational process a success. May be I could not have made it without your supports.

S.S.K. Thotagamuwage

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Chapter 1

INTRODUCTION

1.1 Objectives of the Development

The main objective of this research project is to develop a system for automatic voltage regulation at remote telecom sites and incorporate many of the advanced features & facilities for customized use. It is supposed to be used in remote telecom sites, having day-to-day power quality & continuity problems that frequently interrupt the operation of the critical equipments & services. It is mainly focused on reducing the Diesel Generator operation and frequent customer service outages in the most critical remote sites (backbones of the network), at the 1st stage of implementation.

The final objective of the research is to propose a methodology to reduce the OPEX in telecom operation by advancing the voltage regulating systems available in the market, to best-fit with the telecom requirements.

1.2 Proposed Features

The unit is expected to operate under extreme climatic, environmental & power abnormality conditions to regulate & maintain reliable & accurate sinusoidal voltage profile to the sensitive electronic & telecommunication equipments. In addition, the development of the unit should be capable to meet the protection requirements specified by the equipments installed from environmental & power abnormalities under variety of site conditions. The modular construction for easy customization at initial site installations & easy maintenance at regular intervals is also expected. Increased system efficiency, output power quality, fast voltage correction, long life of operation, noise free regulation, less maintenance attention, automatic monitoring, controlling & operation, relatively small construction with lightweight package at lowest possible cost, are some of the expected outcomes of this development.

1.3 Why the Power Quality is important?

For electrical systems to function properly, it is necessary to make sure that the quality of the power feeding them is of a sufficient quality to ensure that performance is not impaired or system life expectancy reduced.

Without the proper power, an electrical device or load may malfunction, fail prematurely or not operate at all. There are many ways in which electric power can be of poor quality and many more causes of such poor quality. Power supply problems are caused by various sources, for example distribution network faults, system switching, weather and environmental conditions, heavy plant and equipment, or simply faulty hardware.

The most common solution for those power quality problems in industry is to have online UPS (Uninterruptible Power Supply) and will often be viewed as the obvious choice [1]. But, these are usually expensive to buy and have high ongoing maintenance and support costs. In many less developed countries the high technology skill sets required to maintain such systems are not readily and inexpensively available.

For most applications where the loss of mains is not really a critical issue, or can be accommodated by the use of a standby generator, the deployment of an Automatic Voltage Stabilizer / Regulator or AC Power Conditioner will be a far more cost efficient solution both in terms of initial outlay, ongoing maintenance, support costs and the required local skill sets required to install, maintain and support the solution [2]. In other word, over engineering a solution due to a lack of understanding on the power quality issues being experienced is an all too common mistake that can deeply impact.

Regardless of the cause of the problem, the resulting power quality issue will include one, or more, of the power problems as follows [1]. Any system to work under those conditions should be capable to withstand and sustain to operate smoothly.

1.3.1 Voltage Sags

Voltage Sags are short duration decreases in the mains supply voltage which generally last for several cycles. The formal definition is the voltage below 80 to 85% of rated RMS voltage for 2 or more cycles.

The typical symptoms are locking of Sensitive equipment or data loss and system resets. Common Causes of the sags are Heavy equipment turned on, starting large electrical motors, switching of the mains supply.

Commonly available Solutions are AC Voltage Stabilizer, AC Power Conditioner & Uninterruptible Power Supply.

1.3.2 Brownouts

Brownouts are long term sags in the mains supply voltage which can last up to several days. The formal definition is a steady state of RMS voltage under nominal by a relatively constant percentage.

The typical symptom is reset of Equipment or even shutdown. Common Causes of the brownouts are Heavy equipment turned on, starting large electrical motors, switching of the mains supply or just low voltage output from the generating source.

Commonly available Solutions are AC Voltage Stabilizer, AC Power Conditioner & Uninterruptible Power Supply.

1.3.3 Over-Voltage & Surges

Over-Voltage & Surges are short duration increases in the mains supply voltage which generally last several cycles. The formal definition is voltage above 110% of the rated voltage for 1 or more cycles.

The typical symptoms are premature failure & other effects when surges. The high voltage causes wear and tear and general component degradation. This is often unnoticeable until failure occurs. Unusual heat output can be an early sign of problems ahead. Common Causes of this is Heavy equipment being turned off.

Commonly available Solutions are AC Voltage Stabilizer, AC Power Conditioner & Uninterruptible Power Supply.

1.3.4 High Voltage Spikes

High Voltage Spikes are very fast high energy surges or spikes in voltage lasting only a few milliseconds. The formal definition is Rapid Voltage peak up to 6,000 volts with duration of 100msec to ½ a cycle.

The typical symptoms are lock or hang, crash and even suffer damage of equipment which inevitably causes data loss and corruption. Common Causes of these spikes are switching of equipment, especially heavy inductive loads, arcing faults or atmospheric electrical disturbance, such as lightning strikes and static discharges.

Commonly available Solutions are AC Voltage Stabilizer, AC Power Conditioner, Isolation Transformer, and Uninterruptible Power Supply.

1.3.5 Electrical Noise

Electrical Noise is a high frequency noise either common or normal mode. The formal definition is Electrical noise is high frequency interference on the incoming mains supply.

The typical symptoms are Processing errors, computer lock-up, burned circuit boards, degradation of electrical insulation and equipment damage. Common Causes of this noise are Electric motors, relays, motor control devices, broadcast transmission and microwave radiation.

Commonly available Solutions are Isolation Transformer, AC Power Conditioner & Online uninterruptible Power Supply.

1.3.6 Blackouts & Mains Failure

Blackout and Mains Failures occurs when the mains supply fails completely this is known as a total mains failure or blackout. The formal definition is Loss of incoming mains supply.

The typical symptoms are complete disruption of equipment operation. A break in the mains supply of only several milliseconds is sufficient enough to crash, lock or reset many of the components that make up a typical data or voice processing IP network, such as PC, terminal, console, server, PBX, printer, modem, hub or router, if no other back up source is provided.

Common Causes are Storms, lightning, wind and utility equipment failure. Typically occurs as a result of loss of power, a mechanical failure, or overloading by consumers.

Commonly available Solutions are Uninterruptible Power Supply & Diesel Generator.

1.3.7 Summary of the Solutions

Various solutions are available, which provide varying degrees of protection at different prices in the market. They react to changes in the main power supply and are suitable for specific power problems, with varying reaction times and approaches [1]. The performance of some of the solutions under variety of power conditions can be tabulated as follows.

Power Problem	Power Conditioners	Automatic Voltage Stabilizers	Filters and Filter Strips	TVSS	UPS
Sags/ Brownouts	Some	yes	-	-	Yes
Surges	Some	Yes	-	-	Limited
Spikes/ Transients	Yes	Limited	Yes	yes	Yes
Electrical Noise	Yes	Limited	Limited	-	Yes
Harmonics	-	-	-	-	Yes
Frequency variations	-	-	-	-	Yes

Table 1.1: Performance of some the main present power solutions

1.4 Research Area

Under this part of the project, the main concentration is to identify the specific requirements & modifications which needs to incorporated with the basic voltage regulating unit, in order to operate under the telecommunication environments with extremely abnormal site conditions. Selected basic unit will be tested under various site conditions to identify the development requirements and the test results will be analyzed in detail to answer the current issues of the sites which need to be addressed in the first stage. The identified requirements will be implemented to develop a model to suite the tested environment. The final results will be used to present the Technical Feasibility of the project.

At the end of this report, the preliminary theoretical development will be discussed and the proposed equipment arrangement along with the electrical installation modifications will also be identified.

The direct & indirect financial benefits will be identified and the existing operation overhead is suppose to be reduced in greater extend and this will be used to prove the financial feasibility of this project in order to extend the next part of the research development.

1.5 Expected Outcomes

The research development will give the following outcomes in terms of direct financial benefits, operational overhead reductions & much more technical easiness.

Direct Financial Benefits

- Recover the profit/ revenue from network up time
- Customer satisfaction & retention due to unbreakable service
- Reduction of expenses for failure recovery due to power problems
- Minimum part replacements by reducing the equipment failures
- Other financial benefits related to network revenue

Operational Overhead Reductions

- Minimum use of Diesel Generator for the operation
- Minimum attention & visits for day-to-day failure recoveries
- Low routine maintenance visits with reduction of maintenance cost

Technical Benefits

- Improve the efficiency of power to equipments, hence low electricity cost
- Extending the equipment operational lifetime with quality power & reduced interruptions
- Maintain the room temperature in the recommended range for healthy operation as specified by the telecom equipment manufacturers
- Reduce the losses in the equipment operation with high quality power
- Reduced environmental & power surges in to the room and improved protection for the systems
- Etc...

BACKGROUND REVIEW & MOTIVATION

2.1 Power to the Telecom sites

Low Voltage & bad power quality are common problems in most of the Telecommunication Radio Base Stations (RBSs) in Sri Lanka; mainly due to the specific locations of the selected telecom sites to suite the transmission requirements [3]. The best site in terms of transmission can be located at top of mountain or at the middle of a jungle where the coverage & transmission capacity is optimum. However, most of the times, nearest commercial power line are more than 1 ~ 3 Kms away to the mentioned site. Hence the line drawn up to the site will not maintain the standard voltage window, required specially for most of the M&E equipments and the ultimate result is the equipments have to be fed by low voltage supply or request for new Transformer.

2.2 Standard Equipments in BTS

The basic equipment arrangement of a telecom Base Station is as follows.

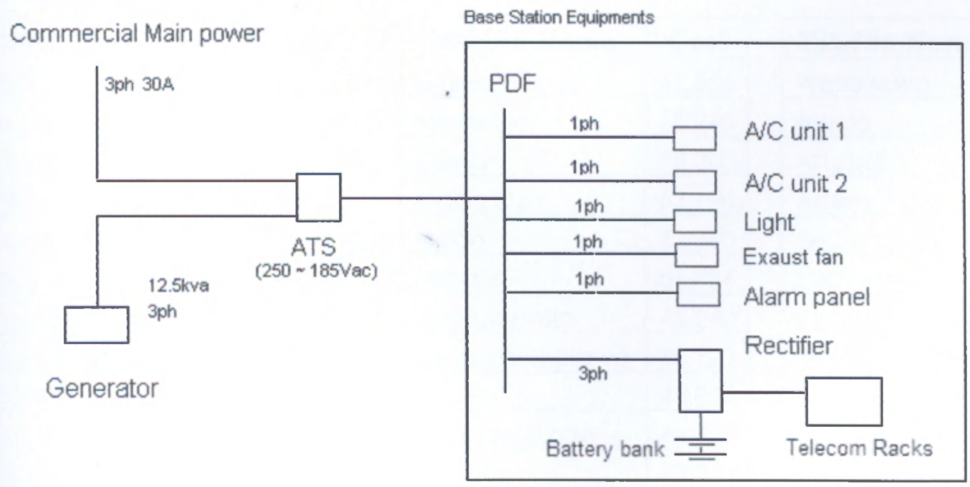


Fig 2.1: Equipment block diagram of standard RBS room.

The line voltage drop is first sensed by the Automatic Transfer Switch (ATS) of the Generator connected and once the voltage goes below than the pre-set limit (most of the time, 185Vac); the Generator will automatically get connected to the system. Note: The single line diagram of ATS panel and equipment power panels can be drawn as per the IEC standard [18] and are annexed at the end.

2.3 Standby Diesel Generator operation due to low voltage

As the voltage profile of the incoming line always drops, the Generator will operate continually and the operation cost in terms of Diesel, portal charges, frequent maintenance & technical attention will be higher. The total cost will exceed around 2 - 3 times that of the normal electricity cost (around Rs. 30,000 per month) and this will indirectly affect the operations cost budget and additions of the same of all the same sites will be a significant figure which will not recommended to extend through out the life of the infrastructure [4].

Some of the previous statistics of Generator diesel cost (month of April 2008) at under voltage sites (owned by Lanka Bell Limited) can be tabulated in descending order as follows. It is observed that the operational cost at sites with significant voltage drops in comparatively high compared to the cost at site where the generator operate only for short period of time.

RBS Site Name	Cost	RBS Site Name	Cost	RBS Site Name	Cost
Rikillagaskada	90,304	Ginigathhena	62,556	Wellawaya	24,986
Mundalama	89,840	Minneriya	58,240	Higula	24,525
Mapalagama	88,200	Kiriella	55,060	Attugala	24,030
Police Park	87,520	Maha Oya	53,196	Adalachchena	23,616
Nildandahena	86,904	Culan	52,360	Badulkubura	23,374
Ulapane	85,998	Robare	51,584	Hettimulla	22,923
Pallebaddara	84,300	Aralaganwila	48,240	Pothuwil	22,568
Ingiriya	82,500	Bogawanthalawa	48,120	Middeniya	22,075
Dompe	78,480	Kohan	45,815	Elpitiya	21,250
Yatiwawala	78,474	Girandurukotte	44,220	Agbopura	20,880
Galenbindunuwewa	74,370	Dabulla	40,902	Rilagala	16,060
Bellwood	73,074	Morawaka	40,080	Sooriyawawa	15,257
Madamahanuwara	72,180	Balangoda	39,195	Naugala	14,819
Pogoda	72,000	Galagedara	38,496	Ambuluwawa	14,436
Gatabaruwa	70,640	Baragala	36,270	Narammala	13,617

Ankubura	69,368	Puliyamkulam	33,760	Belunmahara	13,360
Deniyaya	67,360	Karagahathanna	33,684	Nwalapitiya	13,280
Ibbagamuwa	67,284	Parakaduwa	33,642	Gandara	13,233
Karandeniya	66,550	Madagama	33,046	Warakapola	13,201
Kaudupalalla	64,962	Allawwa	32,841	Nikawaratiya	12,816
Hatharaliyadda	64,962	Hanwella	32,250	Hanguranketa	12,030
Endana	64,080	Diyabeduma	32,160	Kalawana	11,823
Bopitiya	64,000	Jayanthipura	32,160	Palawaththa	11,452
Nittabuwa	64,000	Pitigala	29,650	Waduraba	11,228
Kuruwita	63,920	Awissawella	25,680	Lunuwila	10,160

Table 2.1: Generator Diesel & Potter Cost at Under Voltage sites (network data of Lanka Bell Ltd in April 2008)

2.4 Dedicated Transformers for distance sites

In addition to the above DG cost, some of the sites located faraway to commercial line can not get power in the normal way (as CEB not accepted to provide from the existing lines) and needed to install separate Transformers with huge cost. As the transmission opportunity is much more important, industry will continue with those sites also with huge cost for electricity infrastructure. Some of the same sites with electricity infrastructure cost are listed bellow.

RBS	ROUGH DISTANCE FROM NEAREST HOUSE (m)	DISTANCE FROM CEB OH LINE (Km)	ENGINEERS ESTIMATION FOR LT (Rs.)	CEB ESTIMATION HT (Rs.)	70KVA TRANDFORMER COST (Rs)	TOTAL COST (Rs.)
Hettimulla	500	2.1	600,000.00	4,410,000.00	1,300,000.00	6,310,000.00
Madamahanuwara	200	1.3	40,000.00	2,815,000.00	1,300,000.00	4,155,000.00
Mapalagama	1000	1.4	100,000.00	2,980,000.00	1,300,000.00	4,380,000.00
Ulapane	200	1.0	670,000.00	2,102,200.00	1,300,000.00	4,072,200.00
Galagedara	100	2.8	600,000.00	5,937,750.00	1,300,000.00	7,837,750.00
Ankubura	2000	1.0	750,000.00	2,180,900.00	1,300,000.00	4,230,900.00
Katugastota	400	0.5	650,000.00	1,080,920.00	1,300,000.00	3,030,920.00
Hataraliyadda	50	1.1	775,000.00	2,220,850.00	1,300,000.00	4,295,850.00
Kawdupelella	50	3.2	500,000.00	6,655,000.00	1,300,000.00	8,455,000.00
Niwithigala	100	2.4	5,100,000.00	5,100,000.00	1,300,000.00	11,500,000.00
Ridipana	900	4.8	775,000.00	10,000,000.00	1,300,000.00	12,075,000.00
Nildandahinna	500	2.1	700,000.00	4,418,250.00	1,300,000.00	6,418,250.00
Rikillagaskada	1000	2.0	775,000.00	4,200,000.00	1,300,000.00	6,275,000.00
Morawaka	1200	3.6	775,000.00	7,560,000.00	1,300,000.00	9,635,000.00

Table 2.2: Cost of Transformer installation at CEB unavailable sites (Lanka Bell Ltd)

All the above sites, power can be taken just near to the site with new Transformers purchased by the telecom operator (by Lanka Bell Ltd or shared with other operators in the same site) and voltage problems will not happen. But the cost of the electricity infrastructure is very high & payback period of the investment is beyond the expected.

However, all the other sites which can extend the power line up to the site (accepted by the CEB) have to face with voltage problems and need separate system for voltage regulation [19], [20], [21], [22].

2.5 General applications of Voltage stabilizing systems

In the market, Voltage stabilizing systems can be found for variety of applications. They are suitable for supplying resistive, inductive, and capacitive loads. Automatic Voltage Stabilizers are used at home and abroad, in part under extreme climatic conditions.

They stabilize the power supply for

- Computers, X ray, Laboratories and test facilities
- Industrial electric heaters, Control centers for heating systems, e.g. in hospitals
- Data processing systems, Telecommunication & radio transmission and receiving systems
- Magnetic equipments and Transformers
- Air conditioning equipment, Illumination systems, etc
- Machine tools, motors and Welding equipment

2.6 Effects of supply voltage variations in equipment operation

Automatic Voltage Stabilizers operate on a closed loop control. The output voltage is measured and compared with a highly stable reference voltage in an electronic control unit. Whenever the output voltage deviates from the reference, the servomotor is switched on until the output voltage has again reached its nominal value. This results in a booster voltage, corresponding to the deviation, to be added to or taken away from the line voltage. The correction of the voltage is highly recommended for sensitive equipment operations and more efficient for all other equipments.

Some of the effects under voltage variation conditions can be tabulated as follow [2].

Load	Voltage Reductions Effects	Voltage Increases Effects
Computers	An 8% drop will often cause computer errors and downtime.	A 10% rise will cause computer damage, errors and downtime.
Lighting	A 10% voltage drop reduces lumen output by over 25% (15% for florescent tubes). Infra Red lamp heat output is reduced by over 20.%	A 10% volt rise reduces life expectancy of incandescent lamps by over 50%.
Radio & TV Transmission	Volt drop will reduce quality of the transmission and coverage range.	Over voltage by 2% will significantly reduce tube life.
Photographic Processing	A 5% volt drop will increase exposure times by 30% and reduce quality of color printing significantly.	Voltage rise during printing cycles will cause inferior results
X-Ray Equipment	A 1 % change in the filament voltage of an X Ray tube will produce an 8% change in the anode current.	When used at its maximum rating an X Ray tube will be permanently damaged in the case of a 5% volt rise.
Magnetic Equipment	A 10% volt drop can cause relays / contactors to open chatter. Solenoids become sluggish and vibration will cause malfunctions and overheating.	Over voltage will cause magnetic core saturation high current and overheating. Wear and distortion is increased.
Welding Equipment	A 10% volt drop will increase a welding cycle by 20% if weld quality is to be maintained.	A 10% volt rise will overheat a weld, reducing quality and causing possible "burn through".

Transformers	At 100 kVA a 10% drop will reduce transformer rating to 90%.	A 10% rise will considerably increase core losses and decrease efficiency proportionally.
AC Motors	A 10% volt drop reduces torque by approximately 18%. Motor life expectancy is reduced due to overheating.	A 10% volt rise causes higher starting current and reduces power factor by approximately 5%.

Table 2.3: Effect of voltage variations on equipment operations

The Voltage regulating units available in the market can handle general situations but when the site conditions become complicated, the unit will not support for majority of the operating requirements.

With the requirements identified above, expectation of this research is to develop best suitable unit for voltage regulations with most of the added features [20], [21], [22].

Chapter 3

RESULTS OF SAMPLE SURVEY

3.1 Introduction on the sample site & test equipments

In the above test, Automatic Voltage Stabilizer (AVS) of Servo Motor Type (in-house assembled unit with market available components) installed to one of the inductive load (Air Conditioning unit) at the input point inside RBS and power conditions monitored at various places on the system to identify the variations of the voltage & other parameter under low voltage environment.

The main objective was to understand the operation of AVS and the development requirements which not supported by the AVS unit used.

The environment parameters of the selected sample site are as follows.

Sample Site: Lanka Bell Limited, Kuruwita Base Station.
Test period: 13th July 2008, from 10.30am to 12.30pm
Weather Condition: Light rainfall
Power supply: CEB 30 Amp 1 phase (voltage varied, 100 ~ 250Vac 1ph)

Test equipments used at the above test are as follows.

1 FLUKE 43B Single phase - Power Quality Analyzer
2 KYORITSU AC/DC Clamp Meter
3 Single phase 3KVA, 140 ~ 250Vac, Servo Motor, Automatic Voltage Stabilizer

M&E equipments installed in the RBS can be listed as bellow.

i. HUWEVI BTS 3606 Rack (1 No)
ii. Emerson PS48300 -1A/30-x2 Rectifier rack (1 No)
iii. Air Cooled, Wall mounted, Split A/C, 12,500 Btu/Hr - Mitsubishi (2 No)
iv. F.G.WILSON 12.5KVA Generator (1 No)

v. Bulk Head -Whether Proof Security Light with 7W Compact Fluorescent Lamp (1 No)

vi. 4ft-1x 36W, Surface Mounted Fluorescent Lighting Fixture (2 No)

vii. 2ft-1x8W, Surface Mounted Fluorescent Emergency Fixture (1 No)

viii. 230V,AC, 9" Dia Exhaust Fan with Auto Shutter (1 No)

3.2 Sample Graphs of Voltage & Current distortions

Test graphs obtained from the power quality analyzer at following test points of the power system and the variations of the test parameters can be clearly identified.

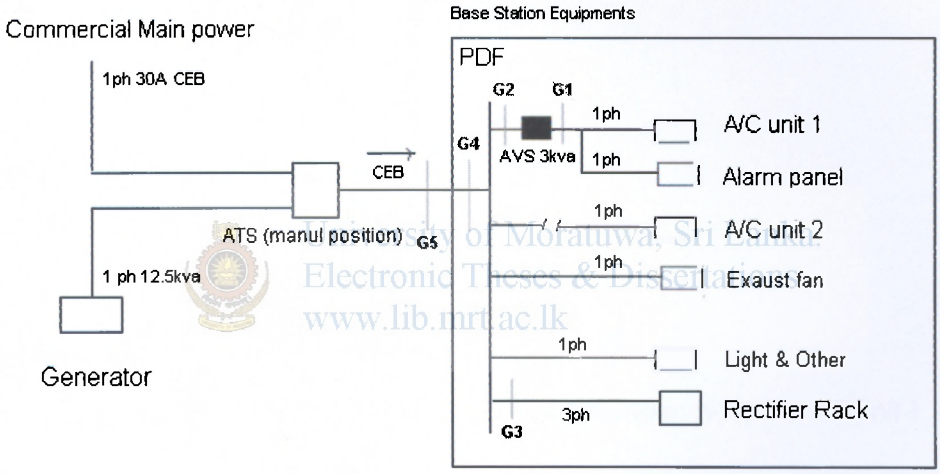
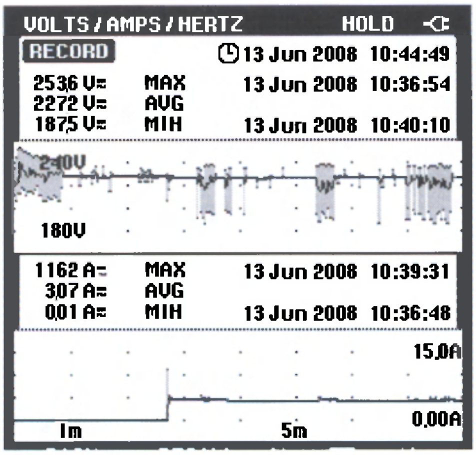


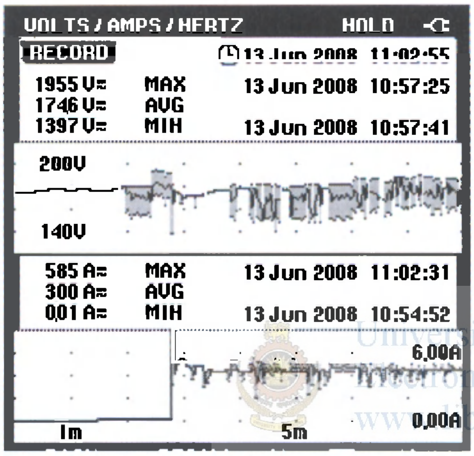
Fig 3.1: Test arrangement of Equipment at Kuruwita Lanka Bell RBS site

The low voltage is a common problem to the distanced/ rurally connected customers and the quality of the power delivered is not suitable to operate sensitive equipments [16].

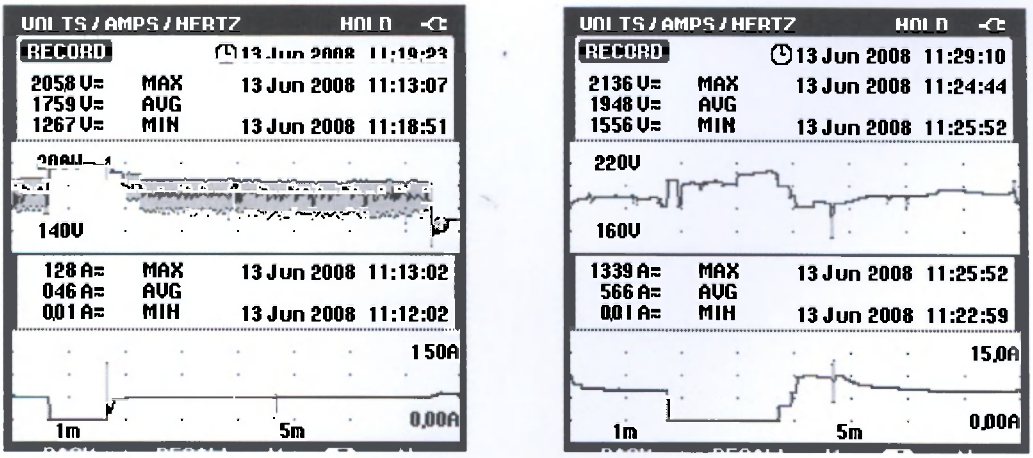
Graphs obtained at points G1 to G5 and the load arrangements are also mentioned below.



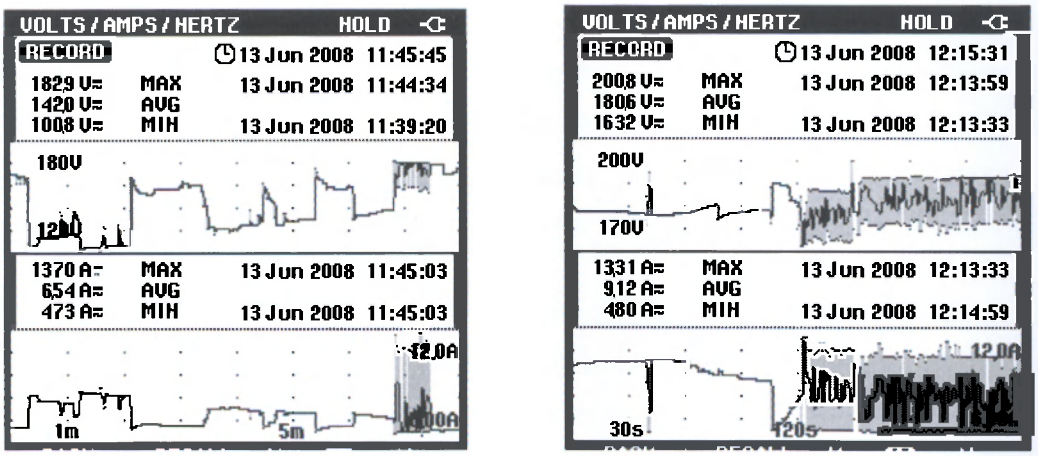
Graph 1 (G1): Stabilizer output (Voltage, Current & Frequency) to the AC unit 1



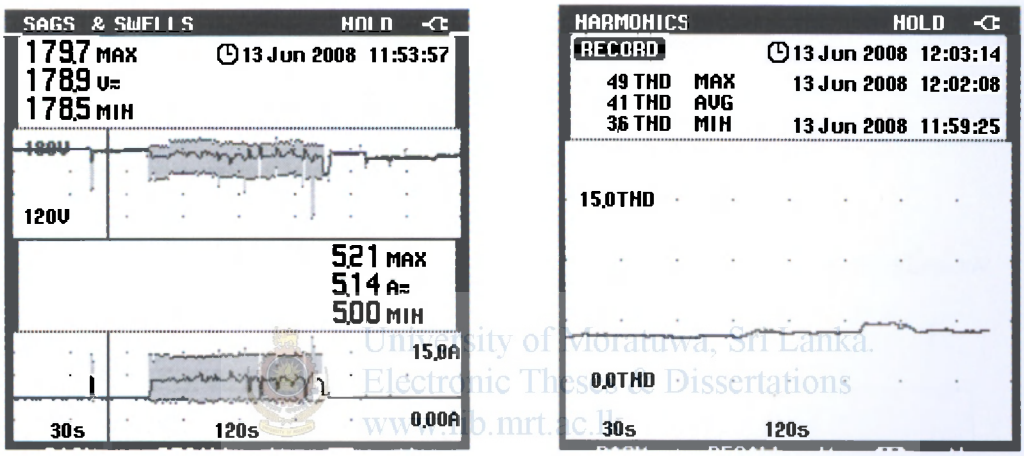
Graph 2 (G2): Normal CEB input (Voltage, Current & Frequency) to the AC unit 1



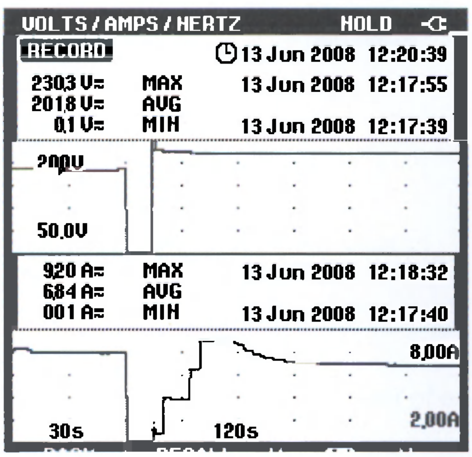
Graph 3 (G3): Normal CEB input (Voltage, Current & Frequency) to the Rectifier Rack (profile with start up characteristics of the Rectifier unit)



Graph 4 (G4): Normal CEB power input (Voltage, Current & Frequency) with all loads



Graph 5 (G5): Normal CEB power input (Sags & Swells and THD) to the cabin with all loads



Graph 5 (G5): Fluctuation (Voltage, Current & Frequency) when transfer CEB to Gen.

With the above test, we understood that the equipments operation with low voltage (high current to deliver same power) will not be accepted as it will damage the insulations & reduce the life of the equipments (observe contactors & relays are vibrating, some relay coils & panel indicators burned, A/C compressor failures due to high current, etc).

However, the low cost AVS will protect the A/Cs, Exhaust and other alarm loads and the Rectifier will operate with low voltage by balancing the input from main & battery to give uninterrupted DC power to BTS.

However, the existing contactors & relays of the ATS panel & power panel need to be replaced with low voltage compatible (140 – 250Vac) types. If all those are compatible, the operation of Generator in the low voltage range could be stopped.

3.3 Suggestions for Voltage correction

The proposed rearrangement of equipments inside the RBS is shown below.

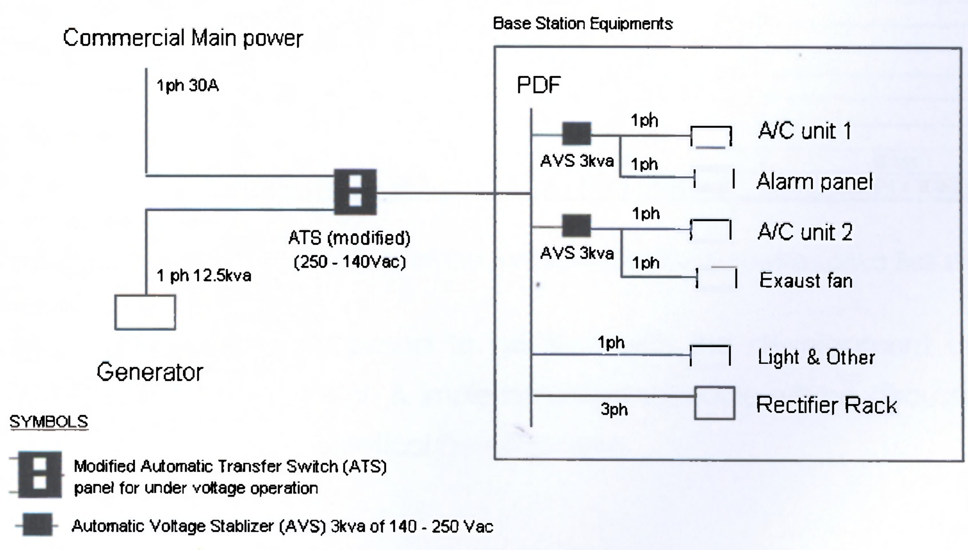


Fig 3.2: Proposed rearrangement of equipments inside the Kuruwita Lanka Bell site

The AC 220Vac (+/- 10%) contactors & control relays of 220Vac (+/- 5%) need to be replaced with low voltage compatible modules such as DC operated coil contractors with 120 ~ 250Vac relays. However the tested AVS operation was limited to the followings and site requirement is much higher than the provided (ex, voltage correction speed was not enough to start the A/C at input voltage around 140 - 170V within stranded 2 – 3 min time, etc).

There are many methods available for voltage corrections in the low voltage distribution network and most of them are application specific. The methods used for one application may not suitable for the other and solutions are case by case basis. However, general solutions are available in low range corrections and various systems can be purchased from the existing market [15].

The following table summaries the Technical specifications of the AVS tested at the Kuruwita Lanka Bell site [17].

	Specifications		
	AVR 1000	AVR2000	AVR3000
Single Phase Input voltage	140~250Vac		
Single Phase Output power	1000 watts	2000 watts	3000 watts
Single Phase Output voltage	230Vac		
Stabilizing Voltage Precision	± 3%		
Frequency	50 Hz		
Adjust Speed	>10V / Sec		
Efficiency	>90%		
Ambient Temperature	minus 10° ~ 40° C		
Relative Humidity	<90%		
Temperature Rise	<60° C		
Waveform Distortion	Non additional waveform distortion		
Power factor of load	0.8		
Withstand Voltage	1500V 1 minute		
Insulation Resistance	>2MΩ		
Manufacturing Standard	ISO 9001		
Weight	5.3 kgs	10 kgs	12 kgs
Dimensions	210 (W) x 165 (H) x 195(D)mm	240(W) x 200(H) x 280(D)mm	240(W) x 230(H) x 300(D)mm

Table 3.1: Technical specifications of the AVS tested at the Kuruwita Lanka Bell site.

The identified gap is supposed to be filled with the development under this project and detailed design & implementation schedule will be discussed in the Chapter 5, under the Theoretical Development.

DEVELOPMENT AREAS & TECHNIQUES

4.1 Proposed Developments

Followings are the proposed features/ development areas with techniques which will incorporate to the Automatic Voltage Stabilizer (AVS) unit specially developed for the telecommunication applications [20], [21], [22].

1. Expanded input voltage window by higher rated windings or power circuits and phase selector to select best available phase.
2. Maintain non distorted sine wave output under distorted input conditions with static line conditioner, Isolation Transformer and RFI/EMI/EMC/EFT filter blocks.
3. Fast respond for voltage correction by small stepped servo transformer
    a. Select servo motor with small steps that can handle lowest min/volt.
    b. Higher voltage correction time by increasing the speed and performance of the synchronous servo motor.

4. Main Controller panel for the overall management of the M&E equipment operations inside the cabin and equipped with Generator selection, Thermal management, Alarm management & logging, Air Conditioner / fan Control, AC distribution customization, power line protection, etc.
5. Protections from power surge, lightning, over current, phase failure, etc by incorporating separate protection systems as per the site conditions
    a. MOVs are added on across the input of the supply line to protect from transient voltage surge or spikes.
    b. Lighting and Surge protection by built in Class-B & C diverters.
    c. Short circuit protection on output side by selecting fuses and the overload protection by thermally or electronically acting trip switches.

d. Coils are wound with paper covered electrolytic grade copper strip or synthetic enameled copper conductors to provide & ensure high short circuit strength.
e. Possess protection & quick isolation of incoming supply under overloading or short circuit conditions by high quality MCB.

6. Higher efficiency of operation by reduced heating, warn out and losses
   a. Reduce the losses of electrical motors which lead to damage of cables, switches, relays, contactors and other associated equipments by regulating the voltage in acceptable range.
   b. Achieve higher reliability & trouble free performance by employing self lubricating carbon roller assemblies instead of ordinary carbon brushes.
   c. Minimize copper losses & iron losses by wound with heavy section of multi strips electrolytic copper and special lamination.

7. Status monitoring capability with alarm extending for remote monitoring
   a. Install analog voltmeters, ammeters, phase indicator lamps, etc as basic indicators on the unit for monitoring the unit status.
   b. Provide advanced indicating options to monitor status of working, excitation, sensing voltage, and even the exact failures of the system itself by extending the alarms to network management center and/ or shown on the unit itself.
   c. Site Status Communication by SMS / GPRS based and RS232 interface support for integration with the remote system and could even be works with CDMA phone.
   d. Additional relay contacts to be operated in a secure manner (guarded by calling party identification) to provide remote control operation at site.

8. Startup delay protection for inductive loads under transient conditions
   a. Include start up delay to preventing any damage to inductive load equipments such as Air conditioners under transient condition and auto restart on main return to within pre-programmed set-point.

9. Rough construction for outstation applications to prevents moisture and contaminants in harsh environments.
    a. Construction with electrically & mechanically reliable components such as variable transformers with motor drive, electronic control units.
    b. The core of voltage controller is constructed from cold rolled, grain oriented, low loss, annealed laminations of electrical sheet steel to make the structure rigid and robust to reduce magnetic noise.

10. Module/ Detachable construction for easy customization to suite the variety of installation, transportation & replacement conditions.
11. Less maintenance attention by component design for extended & un-man operation conditions at remote sites.
12. Incorporate with connected equipments to select the best optimum operation patterns in order to reduce the operation cost while extending the life of operation.
13. Energy saving on connected loads by properly regulated power output.

This unit is a combination of various Functional Blocks that facilitates management of un-man Telecom Sites and a complete standalone site manager which could be ordered with various combinations.to suit every site need.

4.2 Proposed 30 Features – Summery of the Techniques

The development of the stabilizer system will be included with 30 features that specially designed for the telecom applications. The research paper will discuss the technical design, implementation and expected outcomes in detail in the Chapter 5 under Theoretical Development and the summery of the same is tabulated as follows.

	Feature	Methodology	Outcome
1	Expanded input voltage window	Higher rated windings/ power circuits designed on extreme case scenario	Possible to operate under very low or higher voltage
2	Fast respond for voltage correction	Small stepped servo transformer	Load feels minimum of input power changes by maintaining proper RMS output.
		Increasing speed and performance of the synchronous servo motor	
3	Short adjustment time	Servo motor with high starting torque	
4	Stops immediately after switching off & start back in very short time	Self-starting synchronous motor with permanent field	
5	Select best available phase	Phase selector with single phase servo that possible to feed from all 3 phases	Higher reliability in Operation with the best available phase
6	Non distorted sine wave output	Static line conditioner & Isolation Transformer in series to the system	Load receiving true RMS supply from the distorted input power
7	Prevent from RF & EM interference	RFI/EMI/EMC/EFT filter blocks	Load receiving quality supply from the distorted input power
8	Reducing both common mode and differential mode noise emissions		Reduce high frequency emissions from inverters, etc
9	Precise degree of rotation motion	System amplifier with closed loop control circuit	Minimum of output voltage error
10	Protection from transient voltage surge or spikes	MOVs across the input	Precious protection from Voltage surge & spikes
11	Protection from Lighting and Surge	Class-B & C surge diverters placed properly	Precious protection from Lighting and Surge
12	Short circuit protection	Properly selected fuses	Precious protection for equipments on short circuit
13	Over Voltage and Under Voltage protection	Electronic relay monitors the output and activated to disconnect input. Also actuate audible or visual alarms	Protections for the unit under higher or lower voltage when exceeds the design limits
14	Protection from overloading or short circuit conditions	High quality MCB incorporated to the system	Quick isolation of incoming supply under overloading or short circuit conditions

15	Manual or Emergency by-pass	Push button wired also with by pass path from income to load.	Provision to by pass in case of emergency or maintenance time
16	Protections from harmonic currents & improve power factor	Line reactors used	Reduce harmonic currents, spikes, fault currents & save on the electricity costs
17	Output reactors/ chokes	Output reactors/ chokes	Protect motor from over voltage failures associated with long cable runs, Reduces motor temperature & audible noise
18	Higher reliability & trouble free performance of servo motor	Self lubricating carbon roller assemblies on a fiber glass carrier board	Long life of operation without trouble or worn out of brushers
19	Minimize losses in operation	Wound with heavy section of multi strips electrolytic copper and special lamination	Minimize copper losses & iron losses
20	Overall M&E equipment management	Main Controller panel incorporate with equipment in automatic operation	Gen, AC, Fan automatically select only when required
21	Basic status monitoring of the unit	Analog voltmeters, ammeters, phase indicator lamps, etc on the panel front	On site reference on the unit operation and conditions of power
22	Remote Monitoring of the unit status	The dry connectors of the BTS used to extend the alarm to the NOC with relays operated when output tripped off due to exceeded voltages.	Monitoring the failures of the unit remotely and attend immediately for rectification.
23	Auto restart on main return and Startup delay protection	Delay timer on startup after transient conditions.	Prevent damages to inductive load equipments under transient condition
24	Module/ Detachable construction	Each module within the unit facilitate for on site dissemble & reconnecting. PCBs compactly designed and fixed in such a manner that it can be easily removed and reconnected.	Easy customization to suite variety of installation, transportation & replacement conditions

25	Proper maintenance attention	On site instructions on the routing maintenance and scheduled visits for the same. On site minimum spare stocks for easy replacement.	Extended lifetime of the unit with regular maintenance & attentions.
26	Enclosure construction for outstation use	IP 54/55 protection against solid/ liquid ingress. louvers for ventilation and the openings are covered with neoprene gasket for dust proof	Higher reliability in Operation with long life. Prevents moisture and contaminants in harsh environments
27	Electronic components for long hours trouble free operation	Electronic components used of high quality and properly soldered for long hours of continuous trouble free operation. Internal fans for forced ventilation.	Higher reliability in Operation with long life.
28	Lowest in Weight & facilities for movement/ transportation	Use lest weight components for the construction. Include lockable rollers for movement & handles for carrying with connecting supporters.	Easy transportation & movements
29	Low noise operation with minimum friction	Gear arrangements are properly aligned to give smooth, free low noise operation with minimum friction. Used self lubricants on moving parts with auto refilling back once empty.	Noise free & environmental friendly operation
30	Energy-efficient motors	Energy-efficient motors used. Lengthening the core and using lower-electrical-loss steel, thinner stator laminations, and more copper in the windings reduce electrical losses. Improved bearings and a smaller, more aerodynamic cooling fan further increase efficiency.	Lowest in the cost of operation on electricity with higher efficiency on motor operation.

Table 4.1: Summery of the Proposed 30 with techniques & outcomes.

Chapter 5

THEORETICAL DEVELOPMENT

5.1 Development Areas

The proposed development of Voltage stabilizing system will be commenced through the following steps and final output will completely be solution oriented and will best fitted with the real Telecom operational conditions having many & different environment/ power abnormalities.

The theoretical development will be commenced in the following 4 steps.

1. Problem Identification & Categorization:
   Identify the existing equipment arrangements & environmental abnormalities in various Radio base station sites and limitations associated with the existing arrangements.
2. Analyze the problem, solutions & related issues:
   Identify & analyze the problems, limitations & solutions associated with the sites in practice. Categories those RBS sites to few "RBS models" which best represent the overall environment & power situations, in order to implement the solutions in more simple way.
3. Technical approach for the proposed solutions:
   Identify design parameters & theoretical methodologies which need to be considered for the development of proposed voltage stabilizing system and detailed discussion on technical implementations of the real solutions for each RBS models.
4. Improve & enhance the performance of the voltage stabilization system:
   Analyze & design completely telecom oriented voltage stabilizing unit for the given applications with more advanced performance & features.

5.2 Problem Identification and Categorization

<table>
<tr><td colspan="6">360 of RBS sites in operation Island wide</td></tr>
<tr><td colspan="3">110 of RBS sites in Colombo area</td><td colspan="3">250 of RBS sites in outstations</td></tr>
<tr><td colspan="4">333 of CEB/ LECO power available sites</td><td colspan="2">27 of CEB power not available sites</td></tr>
<tr><td>19 of Highly under voltage sites (Gen operate 5 - 10 Hrs per day)</td><td>124 of Voltage marginally stable sites (Gen operate less than 4 Hrs per Day)</td><td colspan="2">190 of Voltage perfect & total Main powered sites</td><td>13 sites under construction with CEB power pending</td><td>14 of full day Generator running sites (Transformer proposed)</td></tr>
<tr><td colspan="2">Voltage stabilization Solution Possible
• 19 sites of Voltage highly dropped (130 – 185V, 1ph)
• 124 sites of voltage marginal (185 V above, 1ph)</td><td colspan="4">Voltage stabilization Solution not possible or not required
• 190 sites of voltage perfect
• 13 sites of CEB pending
• 14 sites of separate transformer proposed</td></tr>
</table>

Table 5.1: Categorization of RBS sites considering power & voltage constrains

The categorization of RBS sites considering power & voltage constrains can be summarized as above (Reference: RBS implementation details of Lanka Bell Limited as on Sep. 2008).

Out of the above 360 sites, Generator operation period at 46 sites are very high (categories underlined in above Table 5.1) and those are due to very low voltage, power unavailability and pending CEB connections.

Reducing the highest Generator operation at those 46 sites is possible only at 19 sites, which is having the commercial power with low voltage. Direct solutions are not possible at other 27 sites. Out of the 27 sites, 14 sites need separate transformer (with huge Capital cost, listed in table 2.2) or need to run only with Generator (with huge operational cost, discussed in Chapter 6) as the CEB is unable to extend the power from the nearest Distribution transformer due to the huge distance up to the site.

5.3 Analyze the problem, Solutions & related issues

Referring the above site conditions, the voltage stabilization solutions can implement in different stages for the 19 sites, as the site & related equipment arrangements are different. Hence, localized solution can be given with few modifications to the existing electrical system. This is more cost saving as each solution is best fitted to the individual site and modifications are also case by case basis, which will avoid generalizing solutions with higher cost.

The low voltage range & occurring time period were obtained at the above 19 sites after several on site observations and the figures are listed in Table 5.2, along with the other important parameters considered.

The sites are categorized under the operational Cluster basis (7 clusters plus Colombo main center for Lanka Bell) and the table also mentioning the available types of the Generator, ATS panel and the power capacity of each site, along with the observed time period of the under voltage as on the nature of the power supply in the given area.

Most of the existing ATS (Automatic Transfer System) of the generator are designed to operate above 185V, 1ph and with low voltage; the coils of the contactors & relays will tend to burn out due to high current. In addition, the power distribution panels & control power systems also designed to operate above 185V as for the general use.

Hence, the above panels need to be modified to operate in under voltage with 48V DC operated contactors (powered by RBS DC battery banks) to make the operating voltage down to around 150V. However, some of the ATS panels are electronic module type and panels can not be modified. Those need to be replaced with new ATS designed by us for low voltage applications.

CASE NO	CLUSTER & RBS NAME	GEN TYPE		ATS TYPE	POWER SUPPLY	UNDER VOLTAGE	GEN RUN TIME	SOLUTION POSSIBILITY
	Kandy							
1	Hatharaliyadde	1	Cummins	Cummins	30A. 1ph	130-140	Continuously	YES
2	Dambulla	2	Cummins	Cummins	30A. 1ph	175-190	4PM-10PM	YES
3	Wahakotte		Pending supply by CEB & already requested.					NO
4	Karagahathanna		No CEB. Gen 24 hrs Running & Transformer needed					NO
5	Madamahanuwara		No CEB. Gen 24 hrs Running & Transformer needed					NO
6	Galagedara		No CEB. Gen 24 hrs Running & Transformer needed					NO
7	Katugastota		No CEB. Gen 24 hrs Running & Transformer needed					NO
8	Ankumbura		No CEB. Gen 24 hrs Running & Transformer needed					NO
9	Kawdupelella		No CEB. Gen 24 hrs Running & Transformer needed					NO
10	Nildandahinna		No CEB. Gen 24 hrs Running & Transformer needed					NO
11	Rikillagaskada		No CEB. Gen 24 hrs Running & Transformer needed					NO
12	Dodangaslanda		No CEB. Gen 24 hrs Running & Transformer needed					NO
	Rathnapura							
13	Kuruwita	3	FG Wilson	ATI63	30A. 1ph	140-160	24Hr CEB	YES
14	Parakaduwa	4	Temast	Hayles	30A. 1ph	160-170	6PM-11PM	YES
15	Neugala	5	Temast	Hayles	30A. 3ph	160-180	5PM-11PM	YES
16	Niwithigala		No CEB. Gen 24 hrs Running & Transformer needed					NO
17	Ingiriya		Pending supply by CEB & already requested.					NO
18	Avissawella		Pending supply by CEB & already requested					NO
19	Endana		Pending supply by CEB & already requested					NO
20	Thalduwa		Pending supply by CEB & already requested					NO
21	Hettimulla		No CEB. Gen 24 hrs Running & Transformer needed					NO
22	Ratnapura		No CEB. Gen 24 hrs Running & Transformer needed					NO
23	Kiriella		Pending supply by CEB & already requested.					NO
	Monaragala							
24	Mahaoya	6	FG Wilson	TI70	30A. 1ph	150-155	Continuously	YES
25	Batticaloa	7	FG Wilson	TI70	30A. 1ph	160-165	Continuously	YES
26	Badalkumbura	8	FG Wilson	TI70	30A. 1ph	170-175	Continuously	YES
27	Medagama	9	FG Wilson	TI70	30A. 3ph	170-180	Continuously	YES
28	Wellawaya	10	Temast	Hayles	30A. 1ph	170-175	Continuously	YES
29	Ridipana		No CEB. Gen 24 hrs Running & Transformer needed					NO
	Matara							
30	Kananke	11	FG Wilson	TI70	30A. 1ph	150-155	Continuously	YES
31	Rilagala	12	FG Wilson	TI70	30A. 1ph	160-170	4PM-10PM	YES
32	Gandara	13	FG Wilson	TI70	30A. 1ph	160-170	4PM-10PM	YES
33	Henaggegoda		Pending supply by CEB & already requested					NO
34	Gatebarukanda		Pending supply by CEB & already requested					NO
35	Mapalagama		No CEB. Gen 24 hrs Running & Transformer needed					NO
36	Morawaka		Pending supply by CEB & already requested					NO
37	Kamburupitiya		Pending supply by CEB & already requested					NO
38	Yakkalamulla		Pending supply by CEB & already requested					NO
	Anuradapura							
39	Minneriya	14	FG Wilson	TI70	30A. 1ph	165-180	Continuously	YES
40	Galenbindunuwew	15	FG Wilson	TI70	30A. 1ph	170-180	5PM-10PM	YES
41	Nochchiyagama	16	Hayles	Hayles	30A. 1ph	170-180	6PM-10PM	YES
42	Jayanthipura		Pending supply by CEB & already requested					NO
	Kurunegala							
43	Rideegama	17	FG Wilson	TI70	30A. 1ph	160-195	Continuously	YES
44	Polpithigama	18	FG Wilson	ATI63	30A. 1ph	160-170	Continuously	YES
45	Maspotha	19	FG Wilson	TI70	30A. 1ph	170-180	5PM-10PM	YES
46	Karuwalagaswewa		Pending supply by CEB & already requested					NO

Table 5.2: Details of RBS sites having highest Gen running & possibility of the solutions

In summary, the above findings will be used to identify the solutions required & best fitted to those sites on individual basis, rather applying general solutions.

Considering all the above factors, the sites can be categorized to the following 5 models to generalize the solutions.

RBS Model	Characteristics of the RBS site	New ATS panel	Modify ATS panel	2 x 3 KVA AVS for A/Cs	8 KVA AVS for main input
0	RBS site with under voltage above 185V and almost stable voltage.	-	-	-	-
1	RBS site with under voltage 170 - 190V and easy access to the site.	-	-	-	√
2(a)	RBS site with under voltage 150 - 185V and existing ATS can be modified.	-	√	√	-
2(b)	RBS site with under voltage 150 - 185V and existing ATS cannot modify.	√	-	√	-
3	RBS site with under voltage bellow 150V and frequent voltage fluctuations.	√	-	√	√
4	RBS sites with no CEB supply & operate on 24hr Generator power.	-	-	-	-

Table 5.3: Categorization of RBS sites to 4 models considering existing site conditions

The sites are categorized with the voltage in 150 – 170V range need only 2 of 3 KVA Stabilizers for two A/Cs and sites with voltage above 170V can be operated only with 8 KVA installed at main incoming line with suitable ATS arrangements.

The sites are categorized with the voltage bellow 150V, need both 2 x 3 KVA (two A/Cs) & 8 KVA (main incoming point) as step-wise voltage improvements is much more reliable and further voltage dropping with connected loads can be avoided with this duel arrangement.

By referring the manufacturer's recommendations for standard Radio base station, the following technical parameters can be fixed for the telecom equipments inside the room [9], [23].

Item	Range
Temperature	Short term: –10°C to +40°C, Long term: 16°C to 26°C (Measured when no solar radiation. Under solar radiation, the maximum values should be 3°C lower)
Temperature change rate	<= 3°C/min
Relative humidity	45% to 85%
Altitude	<= 4,000 m
Air pressure	70 kPa to 106 kPa
Solar radiation	<= 1,120 W/m^2
Heat radiation	<= 600 W/m^2
Wind speed	<= 67 m/s
Input voltage for Rectifier	170 – 250Vac
Input voltage for BTS rack	48Vdc +/- 5%
Input voltage for A/C unit	220 Vac +/- 10%
Input voltage for ATS unit	170 – 250Vac
Input voltage for Flourscent	190 – 250Vac
Input voltage for Exaust Fan	160 – 250Vac
Input voltage for panel indicators	220 Vac +/- 10%

Table 5.4: Environmental requirements of the standard RBS equipments

The proposed equipment arrangement & modifications at the Telecom Radio Base Station can be shown as follows.

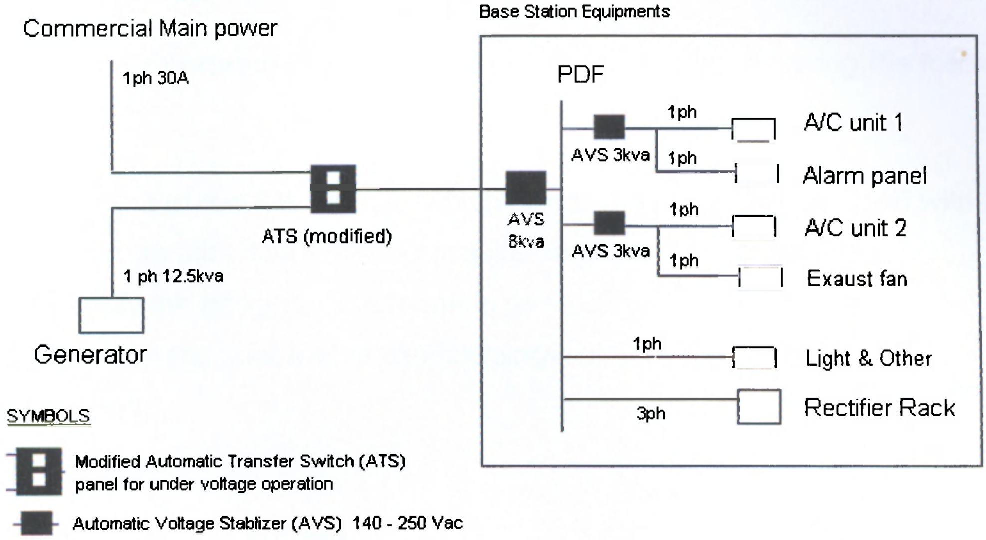


Fig 5.1: Proposed arrangement of equipments inside the RBS site

In addition to the above considerations, the following areas need to be considered before the design of complete system for the voltage stabilization.

1. Input power conditions at each site locations to select the range of stabilization required.
2. Output power accuracy to feed the connected equipments for smooth operation.
3. Protection requirement as per site conditions & equipment specifications.
4. Environmental parameters to design the systems for long lasting operation.
5. Installation, Monitoring, trouble'shooting & maintenance facilities.
6. Energy saving & loss reduction design for operation cost reduction.

Hence, the technical approach for the complete design has to consider all the above parameters in order to implement the complete solution which best fit to the individual site requirements (each RBS Model can be considered), after several on site analysis of actual conditions.

5.4 Technical approach for the proposed solutions

The technical approach of designing the proposed system is having the following 3 phases.

1. Define 3 of the RBS Models (which needs the solutions right now) with their characteristics & operational requirements.
2. Identify the design requirements in general for above RBS model.
3. Propose the theoretical methodology of the AVS design of above RBS models.

5.4.1 Define the RBS Models

The characteristics & operational requirements of each RBS Model can be listed as follows, along with schematically diagrams of the equipments arrangements and detail specifications will be discussed in the table 5.5.

<u>RBS Model 1</u>

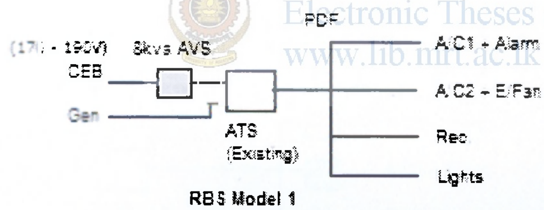


Fig 5.2: Schematic arrangement of Model 1.

- Input voltage in 170 – 190V, 1ph range with short durational variations.
- Access to the site is easy & environmental conditions are stable.
- Sites are located relatively closer to the Distribution transformer.
- RBS room equipped with more complicated electronic equipments and operates as combinations of CDMA, WiMax, Proxi and as backbone center.

RBS Model 2(a)

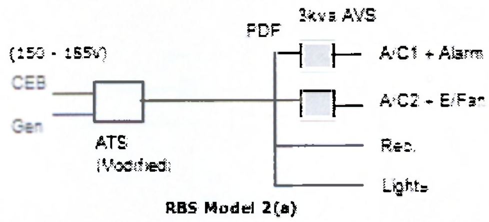


Fig 5.3: Schematic arrangement of Model 2(a).

- Input voltage in 150 – 185V, 1ph range with considerable voltage variations.
- M&E equipments (ATS & PDF accessories) can be modified for low voltage.
- Access to the site is difficult & environmental conditions are also unstable.
- Sites are located far away to Distribution transformer & line averagely loaded.
- RBS room equipped mainly with CDMA equipments and simple operation.

RBS Model 2(b)

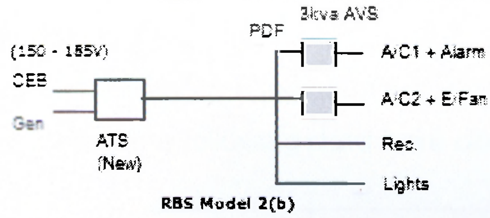


Fig 5.4: Schematic arrangement of Model 2(b).

- Input voltage in 150 – 185V, 1ph range with frequent voltage variations.
- M&E equipments (ATS & PDF contactors & relay controls) are associated with electronics onboard card, sealed type & can not modify for low voltage.
- Access to the site is difficult & environmental conditions are highly varied.
- Sites are located faraway to Distribution transformer & line is loaded.
- RBS room equipped mainly with CDMA equipments and simple operation.

RBS Model 3

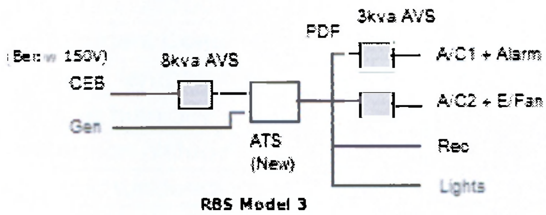


Fig 5.5: Schematic arrangement of Model 3.

- Input voltage below 150V, 1ph range with huge voltage variations.
- M&E equipments (ATS & PDF accessories) are associated with electronic controls with onboard card/ sealed type & can not modify for low voltage.
- Access to the site is difficult & environmental conditions are also unstable.
- More additional protections required for power & environmental abnormalities.
- Sites are located faraway to the Distribution transformer & line is loaded.
- RBS room equipped mainly with CDMA equipments and simple operation.

5.4.2 Identify the Design Requirements for each RBS Model

This is to identify the design parameters in terms of Electrical, Environmental, Protection, Monitoring & Equipment construction requirements for each of the RBS Models in detail. The following data were obtained after several site surveys.

Design Requirements		Model 1	Model 2(a)	Model 2(b)	Model 3
1	**Electrical Data**				
1.1	Rated input voltage	170 – 190V	150 – 185V	150 – 185V	Below 150V
1.2	Input voltage correction	230V - 26%	230V - 35%	230V - 35%	230V - 40%
1.3	Rated frequency	50 Hz	50 Hz	50 Hz	50 Hz
1.4	Mains input capability	10KVA	7.5KVA	7.5KVA	8KVA
1.5	Rated output voltage	230V+/-1%	230V+/-1.5%	230V+/-1.5%	230V+/-3%
1.6	Accuracy of adjustment	99%	98.5%	98.5%	97%
1.7	Output waveform	true RMS	Follow input	Follow input	Follow input
1.8	Response time	0.05 Sec/V	0.05 Sec/V	0.05 Sec/V	0.05 Sec/V
1.9	Efficiency	>95%	>93%	>93%	>90%
1.10	Rated current/ power	8.5 kW	6.5 kW	6.5 kW	7 kW
1.11	Input Power factor	0.85	0.85	0.85	0.85
1.12	Loading balance	balanced	unbalanced	unbalanced	unbalanced

1.13	Loading time	continuous	short-time	short-time	short-time
1.14	Rated short-time current	standard	standard	standard	standard
1.15	Overload Capacity	110%	125%	125%	115%
2	**Environment Conditions**				
2.1	Ambient temperature	27C	25C	25C	20C
2.2	Relative humidity	65%	50%	50%	40%
2.3	Installation altitude	Low	Medium	Medium	High
2.4	Climatic surroundings	Good	Average	Average	Bad
2.5	Bedewing possible	No	No	Yes	Yes
2.6	Pollution possible	Yes	Yes	Yes	Yes
3	**Protection Requirements**				
3.1	Thermal-magnetic overload	Required	Required	Required	Must
3.2	Main on/ off switch	Required	Required	Required	Must
3.3	Transient voltage Surge	Required	Required	Required	Must
3.4	Phase loss sensing	Must	Required	Required	Must
3.5	Automatic output delay on system	Must	Required	Required	Must
3.6	built in IP enclosure	Required	Must	Must	Must
3.7	Installation location	indoor	indoor	indoor	indoor
3.8	Leakage current	Standard	Standard	Standard	Standard
3.9	Earth fault	Standard	Standard	Standard	Standard
3.10	Enclosure ventilation	forced	forced	forced	forced
3.11	Bypass-circuit options	Standard	Standard	Standard	Standard
3.12	Isolation transformer	Required	No	No	Required
3.13	EMI interference filter	Required	No	No	Required
3.14	RFI interference filter	Required	No	No	Required
3.15	Output fuse	No	No	No	Required
3.16	Stall protection for Servo Motors	Standard	Standard	Standard	Standard
4	**Equipment Construction**				
4.1	Available volume				
4.2	Enclosure construction	steel sheet	stainless steel	stainless steel	stainless steel
4.3	Enclosure mounting	stationary	moveable	portable	portable
4.4	Weight of the AVS unit	Allowed	Average	Average	Minimum
4.5	Reliability (MTBF)	Standard	Standard	Standard	Standard
5	**Monitoring Facilities**				
5.1	Phase indication	Standard	Standard	Standard	Standard
5.2	Ampere meter	Standard	Standard	Standard	Standard
5.3	Voltmeter	Standard	Standard	Standard	Standard
5.4	Remote alarm	Required	Optional	Optional	Required

Table 5.5: Design requirements of the RBS Models in detail

5.4.3 Theoretical methodology of the design

The customized design of the voltage stabilizing system should consider the above 3 Models and the final design has to be well fitted with the design requirements. The following areas need to be considered for the development.

1. Design of the Servo Motor system
2. Design of the Autotransformer of the stabilizer
3. Design of the control system of the stabilizer
4. Achieving the highest accuracy of the output Voltage
5. Incorporate protections for the system
6. Maintenance & Monitoring facilities
7. Energy Efficiency, loss reduction & power savings
8. Construction of the unit for rough environment use

5.4.4 Various design technology used in Voltage Stabilizers

Various technologies can be seen on voltage stabilization and the selection will mainly depend on the particular application [5]. Each technology is having different advantages over the other. So, proper selection is much important for the proper operation. The detail design procedures and design advantages/ disadvantages can discuss as follows.

5.4.4.1. Electronic Servo / Electro - Mechanical Design

For most applications, Servo Electronic -Electro Mechanical Ranges have proved to be a very reliable and cost-efficient voltage stabilization solution, being able to accommodate an input voltage swing of in excess of 40% whilst still delivering an accuracy of 1% on the output.

Comprising a transformer having its secondary winding connected between the mains supply and the load, the primary voltage is automatically controlled through a motor driven variable transformer - ensuring a continuous, smooth and very stable output voltage.

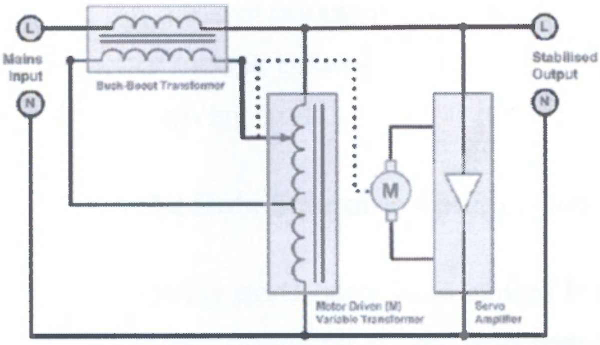


Fig 5.6: Circuit arrangement of Electronic Servo / Electro - Mechanical Design

High Voltage / Transient Spikes are normally limited by the inclusion of 'Spike Clippers'. Such clippers typically limit transients to twice the peak voltage of the supply. To reduce the spikes to totally harmless levels it is often necessary to fit additional Spike Attenuation protection. While Electronic Servo stabilizers do contain some moving parts, experience over many years in some of the most demanding power conditions has proved the design to be a very reliable method of delivering voltage regulation with only a low-level of ongoing maintenance required being deliverable by universally readily available skill sets.

The long-life expectancy, compact size and low cost of ownership makes servo electro mechanical stabilizers economical solutions for a wide variety of applications in industry, commerce, mining, aerospace, computing and telecommunications.

Design Advantages	Design Disadvantages
Size and weight advantages over other methods	Moving parts requiring limited maintenance
Fast speed of response to voltage changes	Lower speed of response compared to solid state designs
Very competitively priced	
Negligible output waveform distortion	
Not Frequency dependent	
Will attenuate voltage spikes if required	
Unaffected by load or power factor changes	
Low cost of ownership with ease of serviceability	
Endurable, with long life expectancy	

Table 5.6: Advantages & Disadvantages of Electronic Servo / Electro - Mechanical Design

Due to the general popularity of this method of voltage stabilization and the high demand for models between 1kVA and 500kVA it is often possible to purchase on short lead delivery times.

5.4.4.2. Solid State Saturable Reactor Design

With no moving parts, solid state design based systems utilize the latest in IGBT control circuitry delivering a very high speed of response and output accuracy maintained to ±0.5%. Since all components are of electronic design, they are virtually maintenance- free

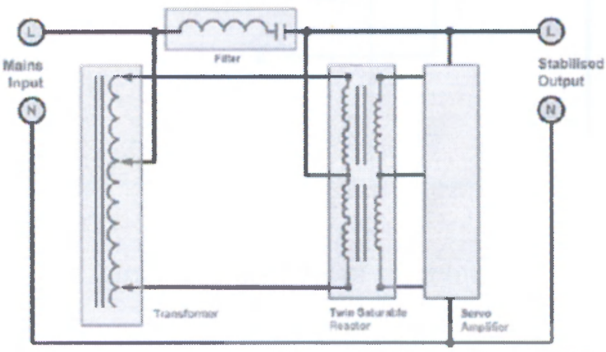


Fig 5.7: Circuit arrangement of Solid State Saturable Reactor Design

Solid state based systems are ideal solutions for equipment that must have output voltage accuracy better than 1%.

Design Advantages ·	Design Disadvantages
High speed of response to voltage changes	Usually less price competitive to Servo Electronic design
Output voltage accuracy typically in 0.5% range	High weight to kVA ratio to electronic servo designs
No Moving parts – virtually Maintenance Free	
High efficiency	
Not Frequency dependent	
Output voltage not collapse on overload or sever input voltage drop	
Low output waveform distortion	
Unaffected by load or power factor changes	

Table 5.7: Advantages & Disadvantages of Solid State Saturable Reactor Design

5.4.4.3. Magnetic Induction Solid State Design

The design technology utilizes a simple, highly reliable, rotor and stator design principle to increase or decrease the magnitude of the voltage in a series transformer winding, which thereby delivers and maintains a constant voltage.

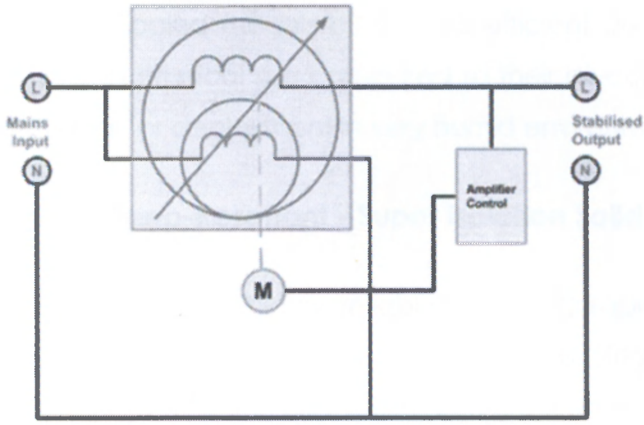


Fig 5.8: Circuit arrangement of Magnetic Induction Solid State Design

Unlike the Servo-Electro Mechanical design, this technology does not require carbon brushes and there is no contact wear. As a result Magnetic Induction based stabilizers are highly reliable and can be viewed as virtually maintenance free solutions.

Design Advantages	Design Disadvantages
High output voltage accuracy	Less price competitive when compared to Servo Electronic design
High reliability	
Virtually Maintenance Free with no contact wear or requirement for carbon brush replacement	

Table 5.8: Advantages & Disadvantages of Magnetic Induction Solid State Design

Available for only larger Three Phase applications above 200 kVA, available in two ranges of Magnetic Induction based voltage stabilization solutions –Air Cooled and Oil Cooled solutions.

As standard Magnetic Induction based stabilizers sense on a single phase and correct for voltage fluctuations simultaneously across all three phases, being suitable for unbalanced loads up to 30%. This is on the other hand offer independent phase sensing / control and are suitable for unbalanced voltages and loads up to 100%.

The Oil Cooled models offer more efficient cooling and as a result tend to be smaller in physical size compared to their air-cooled model. Oil cooled stabilizers are ideal for deployment in very humid environments.

5.4.4.4. Ferro-Resonant - Super Isolation Solid State Design

Based around a highly reliable and endurable Constant Voltage Transformer (CVT), super isolation design based systems (Single Phase AC Power Conditioners) are able to tolerate very wide input fluctuations, even when input voltage drops as low as 40%, the output voltage will be maintained at nominal voltage ±5%.

With no moving parts and no electronic control circuitry there is no need for maintenance and is virtually an install and forgets solution. The design can withstand high instantaneous overloads and is able to suppress lightning induced spikes and surges.

Compact in size and quiet in operation, this design has the inherent ability to withstand a ride-through even when there is a very short power failure, maintaining voltage for 3msecs. This feature is exceptionally useful for sensitive electronic equipment when there are frequent short breaks or severs voltage dips.

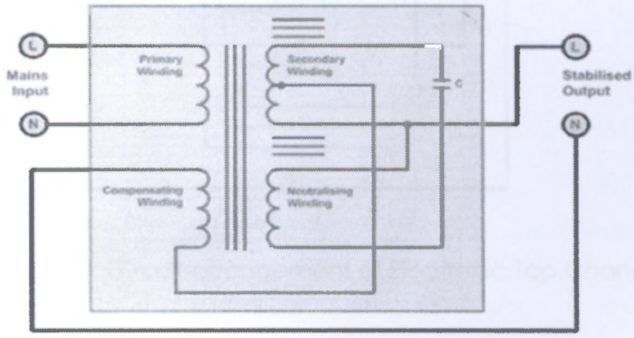


Fig 5.9: Circuit arrangement of Ferro-Resonant - Super Isolation Solid State Design

Design Advantages	Design Disadvantages
High speed of response to voltage changes	Not generally competitive in ratings above 10 kVA
Output voltage does not collapse on overload or sever input voltage drop	High weight to kVA ratio compared to other stabilization methods
Attenuates voltage spikes	Frequency dependent – not ideal for where severe frequency variations are an issue
Competitively priced AC Power Conditioning solution for ratings of 5 kVA or below	
No Moving parts – virtually Maintenance Free	
Highly reliable with extremely high MTBF performance	
Inherent ride-through ability	
Endurable, with long life expectancy	

Table 5.9: Advantages & Disadvantages of Ferro-Resonant - Super Isolation Solid State Design

5.4.4.5. Electronic Tap Changing Solid State Design

The Electronic Tap Changer design principle operates by automatically selecting one of a series of taps on an auto transformer.

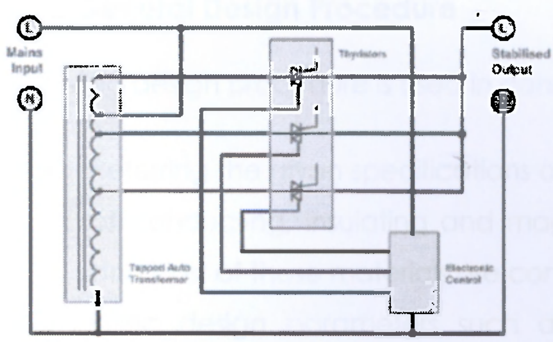


Fig 5.10: Circuit arrangement of Electronic Tap Changing Solid State Design

Design Advantages	Design Disadvantages
Most competitive in price for 2 kVA and below	Poor output voltage accuracy – typically no better than ± 5%
High Efficiency	Generally / historically deliver a low MTBF (Mean Time between Failures)
Negligible output waveform distortion	
No Moving parts – virtually Maintenance Free	

Table 5.10: Advantages & Disadvantages of Electronic Tap Changing Solid State Design

5.5 Design of the Servo Motor system

5.5.1 Aim of the design

The aim of the design is to obtain completely the dimensions of all parts of the machine to furnish these data to the manufacturer. The design should be carried out based on the given specifications and optimize basically to achieve the lowest cost, lowest weight, reduced size and better operating performance [6]. The design is worked out by resorting to various approximation methods based on different formulas, equations, laws, etc. In addition, the design of an electrical machine, must emphasis on lowering cost by saving the materials and reducing labor consume operations to its manufacturer. The design should be satisfactory with respect to electrical strength, mechanical ruggedness, dynamic and thermal resistance of windings in event of short circuit.

5.5.2 General Design Procedure

Following design procedure is used in general for design of servo motor system [6].

- Referring the given specifications of the machine, choose proper materials of conducting, insulating and magnetic parts. The properties, availability and cost of those materials are considered under this stage.
- Basic design parameters such as specific magnetic loading, specific electrical loading, etc are assumed suitably, keeping in view the advantages and disadvantages of higher values of specific loading.
- Design is initiated with the calculation of various dimensions of magnetic and electric circuit, using various design requirements developed.

- Based on the calculated dimensions of the various circuits of the machine, performance of the machine under no load and loaded conditions is predetermined. The temperature rise of the machine, which is of utmost importance is then determined from the calculated values of total losses and the cooling system adopted.
- Calculated performance of the machine is compared with the limiting performance values or customer's requirements. If the performance is not satisfactory, the basic assumption of design parameters needs to be changed, so as to bring the final design closer to the objective.

5.5.3 Constructional & Operational characteristics

Automatic Voltage Stabilizer is an Auto Wound Transformer which is having helical coils mounted on a conventional laminated core [5]. Carbon Rollers assembled on a fiber glass carrier board traverse the length of the Coil Track. These rollers are electrically connected to the output terminals and as they are driven over the track, a variable voltage is obtained. The variations of more than ± 1% of the rated output voltage of the stabilizers are sensed through solid state relay which sends signals to the controlling servo motor which further drives the roller mechanism in such a direction so as to increase or decrease the voltage and stabilize it to the rated output voltage.

Servo motor is responsible for producing mechanical changes from an electromagnetic actuating device.·It is very special type device that is used to achieve a precise degree of rotation motion. Motor must be able to respond accurately to signals developed by the system amplifier. It is also capable of reversing direction quickly when a specific signal polarity is applied. Also, the amount of torque developed by a servomotor is quite high.

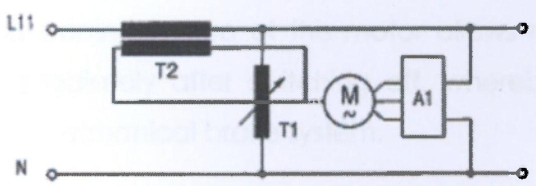


Fig 5.11: Schematic diagram of Servo motor system

(A1 - Control unit, M - Servo drive, T1 - Variable autotransformer, T2 - Booster transformer)

Transformer Core can be manufactured with laminations from Cold Rolled Grain Oriented (CRGO) steel. These laminations are manufactured for distribution and power transformers from 10 KVA to 200,000 KVA and can be mitred (45° angle), V-notched. These laminations are also annealed (to reduce stresses and therefore the watt losses as well as the no load current).

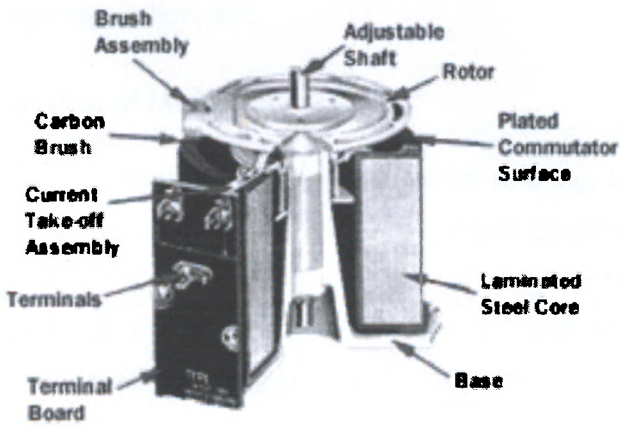


Fig 5.12: Standard assemblies of Servo motor

Auto volt variacs are designed for heavy duty trouble free operations. All components are designed to give maximum life to the unit under extreme operating conditions.

Automatic Voltage Stabilizers are constructed of electrically and mechanically reliable components. Variable toroidal transformers with motor drive, booster transformers, and electronic control units are simple and robust components which assure a long service life.

A self-starting synchronous motor with permanent field is used for the servomotor. The high starting torque of this motor allows relatively short adjustment time; it stops immediately after switching off, whereby the permanent field does not require a mechanical brake system.

5.5.4 Specifications & Design parameters

The initiation of the design of servo motor requires a specifications of main data like output in KVA, line voltage, power factor, frequency, number of phases, type of connections, temperature rise of windings & core, rated speed, overload capacity, etc. Those data can directly be obtained from the table 5.5.

However, certain specifications of performance are usually taken with the experience, such as no load loss, full load current, short circuit current, percentage regulation, etc.

5.5.5 Selection of Materials

The basis of all materials science involves relating the desired properties and relative performance of a material in a certain application to the structure of the atoms and phases in that material through characterization. The major determinants of the structure of a material and thus of its properties are its constituent chemical elements and the way in which it has been processed into its final form [7].

Electrical materials used in construction of all machines can be classified in to 3 groups, named Conducting, Insulating and Magnetic materials. The performance, cost and physical characteristics of the machine will depend on the quality of those materials. If low grade materials are used, the machine would too heavy and costly. Hence, the best practice is to select the proper materials, so as to improve the efficiency, reduce the size, weight and cost with increase of the reliability of the operation [6], [8].

The conducting materials selected should possess the following requirements.

- Lowest possible resistivity
- The least possible temperature coefficient of resistance
- Adequate resistance to corrosion.
- Adequate mechanical strength, especially high tensile strength.
- Good weldability and solderability which ensure high reliability and low electrical resistance of the joints.
- Property of rollability and drawability.

The insulating materials selected should possess the following requirements.

- High insulation resistance
- High dielectric strength
- Low dielectric losses and low dielectric loss angle
- No attraction for moisture
- Capability of withstanding without deterioration a repeated heat cycle
- Good heat conductivity
- Sufficient mechanical strength to withstand vibration and bending
- Solid materials should have a high meting or softening point
- Liquid materials should not evaporate or volatile.

The magnetic materials selected should possess the following requirements.

- High magnetic permeability so that even a weak current flowing in the electromagnet can set up large fluxes in its core
- High electrical resistivity, in order to decrease the eddy current losses occurring in the magnetic materials. This can be achieved by building the core with thin laminations, insulated from each other by varnish. At higher frequencies the thickness of the laminations must be further reduced.
- The hysteresis loop of the magnetic material should be narrow and must have a small area, in order to reduce the hysteresis loss.

The above requirements in respect of materials may vary with the purpose and for the servomotor applications, the selection of the materials will solely depend on the assemblies considered in the individual construction.

5.6 Design of Autotransformer in the stabilizer

An autotransformer has only a single winding with two end terminals, plus a third at an intermediate tap point. The primary voltage is applied across two of the terminals, and the secondary voltage taken from one of these and the third terminal [5]. The primary and secondary circuits therefore have a number of windings turns in common. Since the volts-per-turn is the same in both windings, each develops a voltage in proportion to its number of turns. An adjustable autotransformer is made by exposing part of the winding coils and making the secondary connection through a sliding brush, giving a variable turns ratio.

A failure of the insulation or the windings of an autotransformer can result in full input voltage applied to the output. This is an important safety consideration when deciding to use an autotransformer in a given application.

Because it requires both fewer windings and a smaller core, an autotransformer for power applications is typically lighter and less costly than a two-winding transformer, up to a voltage ratio of about 3:1 - beyond that range of a two-winding transformer is usually more economical.

Autotransformers are frequently used in power applications in power transmission & in industry to interconnect systems operating at different voltage classes. They are also often used for providing conversions between the two common domestic mains voltage bands in the world (100-130V and 200-250V).

On long rural power distribution lines, special autotransformers with automatic tap-changing equipment are inserted as voltage regulators, so that customers at the far end of the line receive the same average voltage as those closer to the source. The variable ratio of the autotransformer compensates for the voltage drop along the line.

As with two-winding transformers, autotransformers may be equipped with many taps and automatic switchgear to allow them to act as automatic voltage regulators, to maintain a steady voltage at the customers' service during a wide range of load conditions.

By exposing part of the winding coils and making the secondary connection through a sliding brush, an almost continuously variable turns ratio can be obtained, allowing for very smooth control of voltage.

5.7 Design of Control system in the stabilizer

Control systems span four major areas: temperature, pressure and flow, voltage and current, and motion. Motion control is implemented with three major prime movers: hydraulic, pneumatic, and electric motors.

Electronic motion control is a multi-billion-dollar industry. Servo motion is a fraction of that industry, sharing it with non-servo motion, such as stepper motors and variable-frequency systems. A servo system is defined here as the drive, motor, and feedback device that allow precise control of position, velocity, or torque using feed-back loops [10]. Examples of servomotors include motors used in machine tools and automation robots. Stepper motors allow precise control of motion as well, but they are not servos because they are run "open-loop," without tuning and without the need for stability analysis.

The most easily recognized characteristic of servo motion is the ability to control position with rapid response to changing commands and disturbances. Servo applications commonly cycle a motor from one position to another at high rates. However, there are servo applications that do not need fast acceleration. For example, web-handling applications, which process rolled material such as tape, do not command large accelerations during normal operation; usually, they attempt to hold velocity constant in the presence of torque disturbances.

Servo systems must have feedback signals to close control loops. Often, these feedback devices are independent physical components mechanically coupled to the motor; for example, encoders and resolvers are commonly used in this role. However, the lack of a separate feedback device does not mean the system is not a servo. This is because the feedback device may be present but may not be easily identified. For example, head-positioning servos of a hard-disk drive use feedback signals built into the disk platter rather than a separate feedback sensor. Also, some applications use electrical signals from the motor itself to indicate speed. This technology is often called sensor less although the name is misleading; the position is still sensed but using intrinsic motor properties rather than a separate feedback device.

The input of a servo system serves as the reference element to which the controlled device responds. By changing the input, a command is applied to the error detector. This device received data from both the input source and from the controlled output device. If a correction is needed with reference to the input command, it is amplified and applied to the actuator. The actuator is normally a servo motor that produces controlled shaft displacements. The controlled output device relays information back to the error detector for position comparison.

The block diagram representation of the above mechanism is shown as follows.

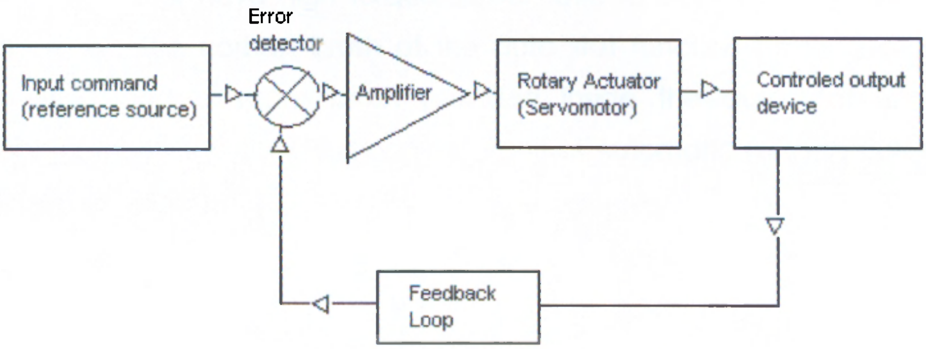


Fig 5.13: Block diagram of a servo system controls

The design of the control system also considered the other arrangement such as ventilation, protection, etc for the reliable operation.

The stabilizer control unit is provided with louvers for proper ventilation and the openings are covered with neoprene gasket for dust proof. Outdoor type stabilizers have IP 54/55 protection against solid and liquid ingress.

The control panel is fixed on the top of auto-stat housing to give a compact design. Proper room for removing and repairing the components is provided. The wiring is neatly done and the components are logically arranged for easy phase wise identification and firmly interconnected.

The closed loop control circuit is of state-of-the art technology and IC based. All Electronic components used of high quality and properly soldered for long hours of continuous trouble free operation at specified site condition. PCBs compactly designed and fixed in such a manner that it can be easily removed and reconnected.

All meters, status / trip indications, control switches etc are placed in front of the control panel and logically arranged phase wise for easy understanding & operation. All indications are of LED type.

Cables contractors and windings carrying the load current are properly design for its duty and current rating. Gear arrangements are properly aligned to give smooth, free low noise operation with minimum friction. AC synchronous motor Stepper motor have high torque/power ratio to achieve high efficiency of the stabilizer. The carbon brush of the auto stat function for long period without wearing and a spare brush provided inside the auto stat for immediate replacement. The standard control circuit of Automatic voltage stabilizer can be shown as follows [11].

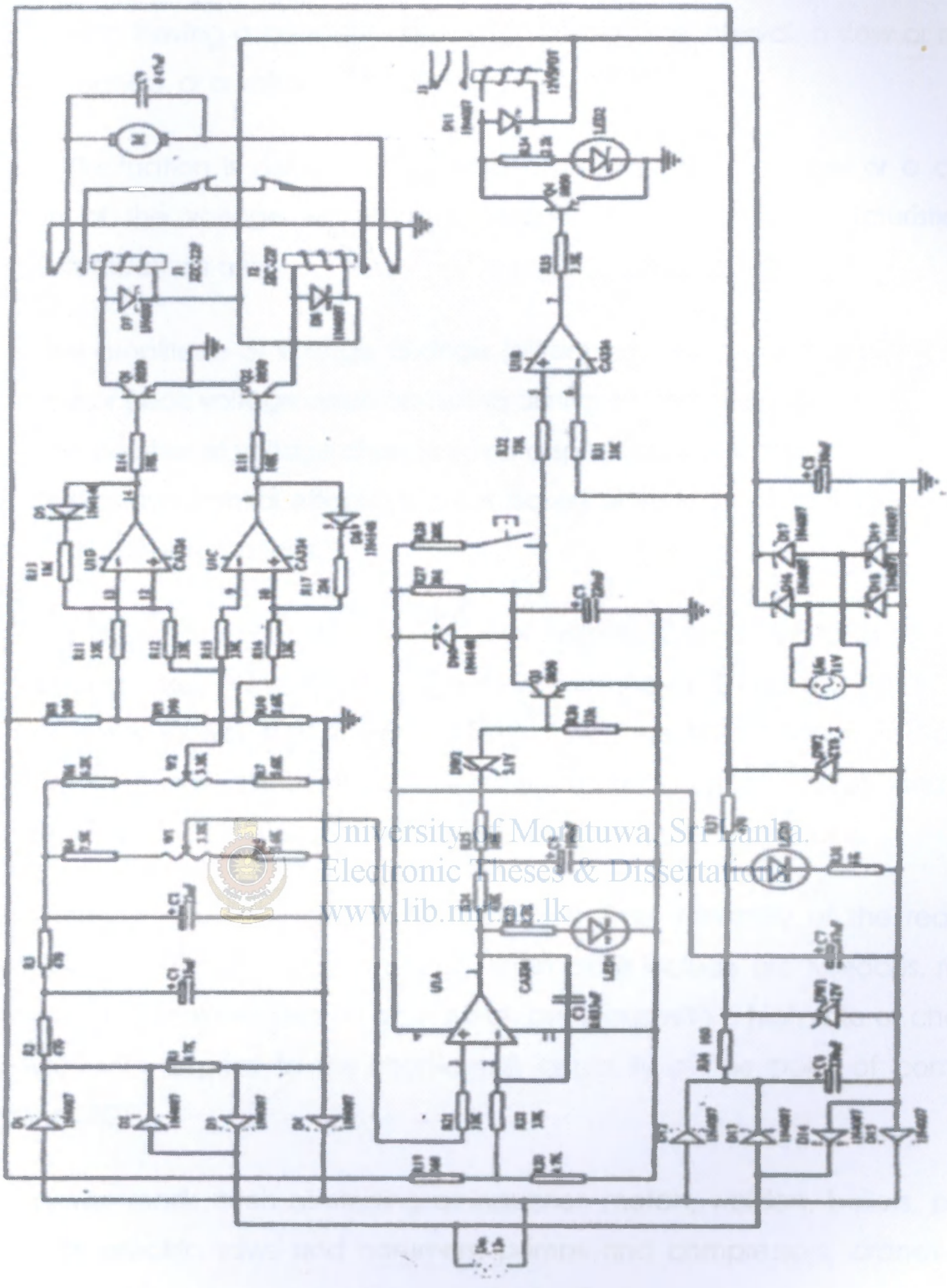


Fig 5.14: Standard control circuit of Automatic voltage stabilizer

5.8 Achieving the highest accuracy of the output Voltage

Voltage fluctuations in power systems can cause a number of harmful technical effects, resulting in disruption to production processes and substantial costs. Theoretically, for any supply line, the voltage at the load end is different from that at the source. Depending on its cause, a voltage change can take the form of a voltage drop having a constant value over a long time interval, a slow or rapid voltage change, or a voltage fluctuation.

Voltage fluctuation is defined as a series of rms voltage changes or a cyclic variation of the voltage waveform envelope. The defining characteristics of voltage fluctuations are:

- The amplitude of voltage change (difference of maximum and minimum rms or peak voltage value occurring during the disturbance);
- The number of voltage changes over a specified unit of time; and
- The consequential effects (such as flicker) of voltage changes associated with the disturbances.

Until recently, voltage fluctuations in power systems, and at the load terminals, were characterized using factors associated with the peak-to-peak rms voltage change in the power system. The energy of voltage fluctuations, their power spectrum (also called the energy spectrum of voltage fluctuations), and their duration were taken into account when assessing voltage fluctuations.

The primary cause of voltage changes is the time variability of the reactive power component of fluctuating loads. Such loads include arc furnaces, rolling mill drives, and main winders — all of which are loads with a high rate of change of power with respect to the short-circuit capacity at the point of common coupling (PCC).

Small power loads, such as starting of induction motors, welders, boilers, power regulators, electric saws and hammers, pumps and compressors, cranes, and elevators also can be sources of voltage fluctuations.

Other causes are capacitor switching and on-load transformer tap changers, which can change the inductive component of the source impedance. Variations in generation capacity of wind turbines, for example, also can have an effect. Sometimes, voltage fluctuations are caused by low-frequency voltage inter-harmonics.

The effects of voltage fluctuations depend first on their amplitude, which is influenced by the characteristics of the power system, and second, on the rate of their occurrence, which is determined by the type of load and character of its operation. Usually, mitigation measures focus on limiting the amplitude of the voltage fluctuations. The technological process is seldom influenced.

Examples of mitigation methods for various types of equipment include:

- Arc furnaces — Incorporate series reactors (or variable saturation); ensure proper functioning of the electrode control system; segregate and provide preliminary heating of charge.
- Welding plants — Supply the plant from a dedicated transformer; connect single-phase welders to a 3-phase network for balanced load distribution between phases; connect single-phase welding machines to different phases from those powering lighting equipment.
- Adjustable speed drives — Use soft-start devices.

Another way to reduce the amplitude of voltage fluctuations is to increase the short-circuit power with respect to the load power, at the PCC to which a fluctuating load is connected. This can be done by:

- Connecting the load at a higher nominal voltage level;
- Supplying this category of loads from dedicated lines;
- Separating supplies to fluctuating loads from steady loads by using separate windings of a three-winding transformer;
- Increasing the rated power of the transformer supplying the fluctuating load; or
- Installing series capacitors.

Yet another way to reduce the amplitude of voltage fluctuations is to reduce the changes of reactive power in the supply system. This can be done by installing dynamic voltage stabilizers. Their effectiveness depends mainly on their rated power and speed of reaction.

By drawing reactive power at the fundamental frequency, dynamic voltage stabilizers produce voltage drops on the supply network impedances. Depending on whether the reactive power is inductive or capacitive, the rms voltage value at the PCC can be increased or reduced.

Standard adjustment or accuracy ranges of AVSs are usually arranged symmetrically. For unsymmetrical adjustment ranges, e. g. from + 5 %/ - 10 % up to + 10 %/ - 30 %, can be seen.

The correction time is determined by the speed of the synchronous servo motor; it is directly proportional to the frequency. In addition, it is affected by the adjustment range.

5.9 Incorporate protections for the system

Many protection schemes can be incorporated with the AVS system as per the site conditions and some of them are described below.

5.9.1 Short-circuit and overload protection

Carefully selected fuses protect against short-circuits on the output side, thermal or electronically acting trip switches can be provided for overload protection. It should also be noted that the power networks with lower capability, the higher currents occurring at low input voltage result in an additional voltage drop, which the control can no longer equalize. In such cases, detailed information concerning the characteristics of the power network are required for optimal determination, e. g. distance to next transformer station, line cross-section, type of wiring (buried cable, high line), line impedance, short circuit power, etc.

5.9.2 Over and Under Voltage protection

The electronic relay continually monitors the output voltage and is activated if the output voltage deviates by ±5% of the preset level. It can be used to actuate audible or visual alarms, or contactors.

5.9.3 Safe Start, Bypass and Circuit Breaker protection

Safe start ensures that the output voltage is at a minimum, at the moment of switch-on, before stabilization takes place.

Manual bypass switches can be supplied for remote mounting to enable the transfer of load directly to the incoming supply thereby isolating the stabilizer.

Input and/or output MCBs or fuses can be fitted when required.

5.9.4 Lightning & Surge Protection

Lightning arresters can be used to protect system against induced lightning strikes. Where high voltage transients and spikes are expected to be present on a power system, surge arrestors help to protect sensitive electronics equipment. Additional protection can be added as a safeguard to sensitive loads from Noise, Spike and Transient Protection.

5.9.5 Auto/Manual Control & Emergency by-pass

A toggle switch is provided to switch the stabilizer on Auto or Manual mode. In Auto mode the output corrected automatically in closed loop control to give the specified output Voltage. Provision to adjust the set value within the specified is also being provided. In Manual mode an increase decrease push button is provided to adjust the output voltage.

Provision to by pass is provided to switch on the output in case of emergency and at stabilizer maintenance time.

5.9.6 Line / Output Reactor

Line reactors are used to reduce harmonic currents and thus the power factor of the current drawn by power electronic equipment. At the same time they reduce spikes caused by disturbances on the power supply and they will reduce the level of potential fault currents. Thus as well as protecting the equipment they help save on the electricity costs. In addition, this also helps to reduces surge currents, reduction in harmonic distortion, Improves true power factor and elimination of nuisance tripping from power line spikes.

Output reactors, otherwise known as chokes, can also be used on the output side of an inverter drive to protect a motor from over voltage failures associated with long cable runs. The advantages of using an output reactor with a variable speed drive are, Protection of motors from long cable effects, Reduction of output voltage dv/dt, Reduces motor temperature & Reduces motor audible noise.

5.9.7 RFI / EMI Filters

RF filters offer a solution to many interference problems in a plant caused by the high frequency emissions from variable speed motor drives and inverters. Type RF filters can prevent drives and inverters from interfering with other sensitive electronic loads by reducing both common mode and differential mode noise emissions.

5.9.8 Sine Wave Motor Protection Filters

These filters are for use on the output side of an AC inverter and convert the PWM current from a variable speed drive into a near perfect sine wave at the motor terminals. They are ideal for use when long power cables are necessary and on older motors where the insulation quality may be less than a modern motor.

Sine-wave Filters reduce motor insulation stress and eliminate switching acoustic noise from the motor. Bearing currents are also reduced, especially in larger motors above 50 kW.

Sine-wave filters prevent disturbing pulses from being transmitted to the motor. Capacitances in screened motor supply cables can otherwise cause high oscillating circuit currents through motor bearings, vaporizing lubricant and causing damage to the bearings.

The eddy current losses in the motor can also be minimized in this manner, resulting in a cooler motor and thus extended motor life-time. In addition to protecting the motor, the sine-wave filter also provides protection for the inverter, because the lower pulse load is reflected in lower semiconductor losses.

It should however be noted that this filter does not operate in common mode and the leakage currents are not reduced, therefore it does not enable the use of unlimited motor cables lengths.

Some of the Benefits are reduces voltage peaks in motor, prevents flashover in motor windings, diminishes over voltages and voltage spikes caused by cable reflections, protects the motor insulation against premature aging, reduces du/dt stresses which Increases motor service interval, lowers the magnetic interference propagation on surrounding cables and equipment which help for trouble-free operation, eliminates acoustic noise in motor which helps on noiseless motor operation and reduces high frequent losses in motor that helps on prolongs service interval of motor.

5.10 Maintenance & Monitoring facilities

Regular inspection and preventive maintenance assure reliability and long service life. Some of the important preventive maintenance procedures are as follows.

1. Check all terminals and contacts; pay particular attention to the PE-terminals and their connection.
2. Examine all moving parts for faultless function, position, and fastening.
3. Inspect position and function of limit switches.
4. When necessary clean and lubricate the driving gear assembly. Never lubricate carbon rolls, their axis, or contact paths.
5. When necessary clean carbon rolls and contact path with cloth or paint brush. Surfaces covered with heavy oxide must be cleaned with only non-permanent silver-polish. Immediately wipe again with cloth, soaked in denatured alcohol. Be careful with inflammable materials! Never use emery-cloth or solvents, these materials destroy the contact path as well as the insulation of windings.
6. Check the contact surface of carbon rolls and their pressure visually and manually. The contact pressure of carbon rolls should be about 2-3 kg each. Damaged carbon rolls must be replaced immediately.
7. Check the easy movability of carbon rolls and their holders manually.
8. Keep an inspection book for recording the services at site.

Timely replacement of carbon tips and cleaning of the commutator surface of foreign particles and accumulated dust will ensure a considerably long, maintenance free and interrupted life to the unit.

The dry contact signals on all type can be extend through the base station signal path and the contact points should be connected directly.

Analogue or digital volt/amp meters can be fitted and include phase selector switch on three phase models for the indication of input/output phase voltages or output phase currents.

5.11 Energy Efficiency, loss reduction & power savings

Energy is a limited resource for the whole world and need to manage the usage and reduce the wastages. From small user to large industry, the effort & strategies for energy saving is much more important. This is because, the future is unpredictable and if our civilization is to survive; we cannot stray far from the following scenario [12], [13].

1. We are rapidly exhausting fossil fuels.
2. Future must depend on non-fossil ("renewable" and other) energy sources.
3. Replacement sources probably can supply only a fraction of current usage.
4. Therefore, we must maximize energy efficiency and energy conservation.

The following graph clearly explains the gap between the oil discovery and expected consumption of the world market. Hence, every project should deeply consider on the possible energy savings.

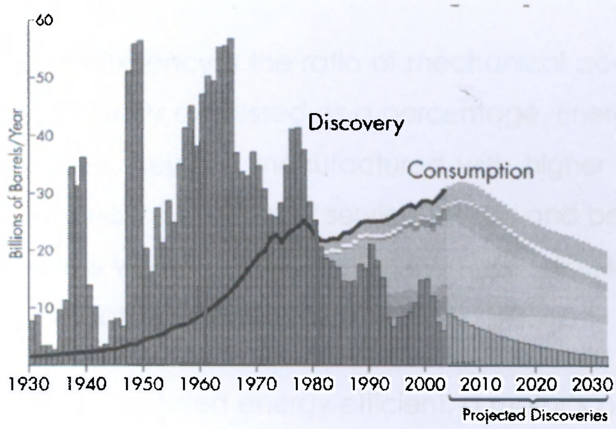


Fig 5.15: The growing gap of the Peak oil discovery and the world consumption

Hence, as the energy serving is much important, this development also, considered the possible energy savings on various areas, such as Servo motor efficiency improvement, BTS equipment operation management, etc and the key areas are discussed as below.

The key benefits from the energy efficiency are Increased the life of equipments, optimize recycling, Improve operational efficiency, less electricity cost, better plant management, etc.

5.11.1. Energy-Efficiency in Motors

Efficiency is an important factor to consider when buying or rewinding an electric motor. Over 70% of all electrical energy consumed in most of the industry is used by electric motors. Improving the efficiency of electric motors and the equipment can drive to save energy and reduce operating costs [14].

Energy efficiency should be a major consideration when purchasing or rewinding a motor, as well as the more common considerations is the purchase price and delivery time. The annual energy cost of running a motor is usually many times greater than its initial purchase price.

Energy-efficient motors owe their higher performance to key design improvements and more accurate manufacturing tolerances. Lengthening the core and using lower-electrical-loss steel, thinner stator laminations, and more copper in the windings reduce electrical losses. Improved bearings and a smaller, more aerodynamic cooling fan further increase efficiency.

Motor efficiency is the ratio of mechanical power output to the electrical power input, usually expressed as a percentage. Energy-efficient motors use less energy. Because they are manufactured with higher quality materials and techniques, they usually have higher service factors and bearing lives, less waste heat output, and less vibration, all of which increase reliability. This is often reflected by longer manufacturer's warranties.

To be considered energy-efficient, a motor's performance must equal or exceed the nominal full-load efficiency values provided by the National Electrical

Manufacturer's Association (NEMA) in their publication MG-1. The Energy Policy Act of 1992 (EPACT) required most general purpose motors between 1 and 200 horsepower for sale in the U.S. to meet these NEMA standards by October 24, 1997. However, no such standard applicable in Sri Lanka, but the measures are much valid from the operational point of view.

Assuming kWh electricity cost and payback criteria, most motors should be replaced with an energy-efficient model if they operate considerable hours per year in their operations. In general, energy-efficient motors should be considered in the following circumstances:

1. New installations, both separate and as part of packages
2. When modifications are made to a facility or a process
3. Instead of rewinding older, standard-efficiency motors
4. As part of a preventive maintenance or energy conservation plan

5.11.2 Determine Cost Effectiveness of the Motors

The cost effectiveness of an energy-efficient motor in a specific situation depends on several factors, including motor price, efficiency rating, annual hours of use, energy rates, cost of installation and downtime, and the availability of utility rebates or other incentives [14].

The following design characteristics are Important when selecting a motor for the particular applications.

- Motor Size: Motors should be sized to operate with a load factor between 65% and 100%. The common practice of over sizing results in less efficient motor operation.
- Operating Speed: While the average speed of energy-efficient motors is slightly higher than the average speed of standard-efficiency motors for any given size, models of each type are available with a wide range of speeds. Installing a new motor with a higher speed can result in diminished energy savings. It is particularly important in centrifugal pump or fan applications to select replacement motors with a comparable full-load speed.

- Inrush Current: Avoid overloading circuits. Energy-efficient motors feature low electrical resistance and thus exhibit higher inrush currents than standard models. The inrush current duration is too short to trip thermal protection devices, but energy-efficient motors equipped with magnetic circuit protectors can sometimes experience nuisance trips during start-up.

Energy-efficient motors should be considered for all new installations, replacement of failed motors, or as spares. They are frequently a cost-effective alternative to rewinding, and are sometimes an economic substitute for well-functioning motors in high-duty applications.

However, in cases where the faster speed of the energy-efficient motor results in higher energy use without adding to the useful work performed, the energy-efficient motor may not be an economic option. A cost comparison will determine if a motor replacement is cost effective, and an analysis of the whole system--including the driven process, drive train, and controls—can reveal if other changes could provide greater benefits.

Energy-efficient motors generally have longer insulation and bearing lives, lower heat output, and less vibration. In addition, these motors are often more tolerant of overload conditions and phase imbalance. This results in low failure rates, which has prompted most manufacturers to offer longer warranties for their energy-efficient lines.

Purchasing an energy-efficient motor can dramatically cut energy costs. Energy-efficient motors have a strong track record of high performance, with proven lower failure rates. As with all motors, materials and components can degrade during repair and rewind, reducing the original efficiency level. Insisting that the motor repair shop adhere to recommended quality standards can help maintain motor efficiency at or near original levels.

5.11.3 Energy optimization of the equipments in Telecom operation

The standard Telecom base station comprises of various equipments and the energy used by those equipments can be optimized by any of the followings [13].

1. Replace more energy efficient equipment with existing sets
2. Rearrange the equipment (especially Air Conditioners) to get the best operational efficiency in order to reduce the electricity cost
3. Redesign the shelter envelops to minimize the energy used mainly for the cooling purpose
4. Automate the equipment (power & A/C) operation to get the minimum energy use in operation by allowing each set of units to operate only when required
5. Select the power source as Diesel Generator only when the main is not available (Blackout) and voltage is extremely lower by modifying the power equipments to operate under any low voltage with AVS and replace with low voltage sensitive power equipments

Out of the following equipments used in telecom site, the energy efficient replacements can be found from the market and proposed to replace. This will benefit as higher energy cost reduction, lower capacity of equipments, extended life of the equipments, improved total operation, etc.

The existing equipment and the proposed efficient replacements can be tabulated as follows.

Existing Equipment	Energy Efferent Replacement
HUWEVI BTS 3606 Rack (*6Amp*)	Newer version BTS rack (*4Amp*)
Emerson PS48300 Rectifier rack	Newer version Rectifier rack
Split A/C units, 12,500 Btu/Hr (*6Amp*)	Inverter type A/C 9,000 Btu/Hr (*1Amp*)
12.5KVA Prime Generator	7.5 KVA Standby Generator
Bulk Head - Light with bulb (*100W*)	Bulk Head - Light with CFL (*7W*)
4ft 36W Fluorescent Fixture with magnetic ballast (*0.7Amp*)	2ft 18W Fluorescent Fixture with electronic ballast & PF cap. (*0.2Amp*)
Emergency Lighting Fixture (*75W*)	Energy saving portable Emergency Lighting unit (*40W*)
9" Exhaust Fan (*2Amp*)	9" Energy saving Exhaust Fan (*1.2Amp*)

Table 5.11: Energy efficient equipment replacements for telecom sites

5.12 Technical Analysis on the Power Quality of LV network

5.12.1 Introduction on Power Quality

Any power problem manifest in voltage, current or frequency deviations that results in the failure or malfunction or miss operation of equipment [24]. Most of the power and telecom system equipments such as Power electronic equipments and Microprocessor base equipments are sensitive to PQ variations. Use of more electronic equipments will results more PQ problems. The voltage plays major roll in the PQ and can be considered as the most ordinary phenomena representing the PQ.

The effect of poor PQ are Interrupt supply, Damage sensitive data processing, control & instrumentation equipments, Loss of product quality and efficiency, Light flickering, Over heating of transformers, motors, capacitors, Loss of plant capacity/ life time and mal-operation of tariff meters.

5.12.2 Mathematical modeling of Load level voltage fluctuation

Consider the simple model representing a fluctuating load drawing real power P, and reactive power Q, connected to a power system with impedance of resistance R, and reactance X, as illustrated in Fig. 5.16. The voltage V_R seen by the customer can usually be regulated by operating the system voltage V_S at a slightly higher value to ensure V_R remains at the required value, e.g. 230V for a single-phase system. During steady state operation this can be achieved through the use of automatic tap changers on transformers, line drop compensators and voltage stabilizers. For more rapid changes in load current the operation of such devices is not fast enough in response to effectively regulate the voltage to stay at the required value [24].

The resultant voltage due to the current drawn by the load is illustrated in the phase diagram of Fig. 5.17 where V_S is the supply voltage and V_R is the resultant voltage seen by the load at the point of common connection (PCC).

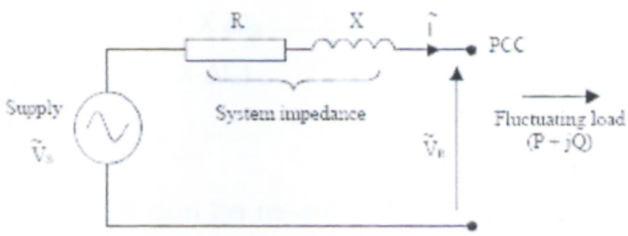


Fig 5.16: Simple model of power system

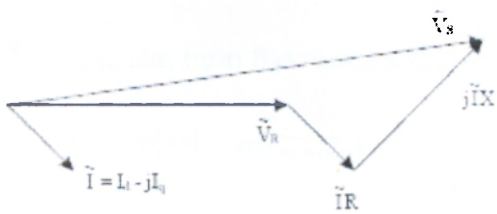


Fig 5.17: Phase diagram of supply voltage

The complex power drawn by the fluctuating load and the voltage phases can be described by equations (1) and (2) respectively.

$V_R I^* = P + jQ$ .... (1)

$V_S = VR + I\ (R + jX)$ .... (2)

Expanding equation (2) for the voltage phases provides the following

$V_S = V_R + (I_d - jI_q)\ (R + jX)$ .... (3)

$V_S = (V_R + R\ I_d + X\ I_q) + j(X\ I_d - R\ I_q)$ .... (4)

Ignoring the phase differences between V_R and V_S in equation (4) and equating only the real parts

$V_S = V_R + R\ I_d + X\ I_q$ .... (5)

Assuming V_S is a very strong supply system, i.e. V_S remains constant regardless of the current drawn by the fluctuating load, for any changes in I_d and I_q the changes in V_R will be as follows

$0 = \Delta V_R + R\,\Delta I_d + X\,\Delta I_q$ .... (6)

$\Delta V_R = -\,(R\,\Delta I_d + X\,\Delta I_q)$ .... (7)

Equation (7) can be re-written in per unit, i.e. in terms of the changes in real and imaginary power drawn by the fluctuating load

$\Delta V_R = -\,(R\,\Delta P + X\,\Delta Q)$ .... (8)

If R is negligible, then the reactance X = 1 / Fault level, leading to equation (9)

$\Delta V_R = -\,\Delta Q$ / Fault level .... (9)

Thus, it can be seen that the voltage at the point of common connection is essentially a function of the reactive power variation of the load and supply system characteristics.

Note that for low voltage systems where R is considerably larger the real power may also contribute significantly to voltage variations.

The above ΔV_R voltage correction range can be corrected by the Voltage stabilizer.

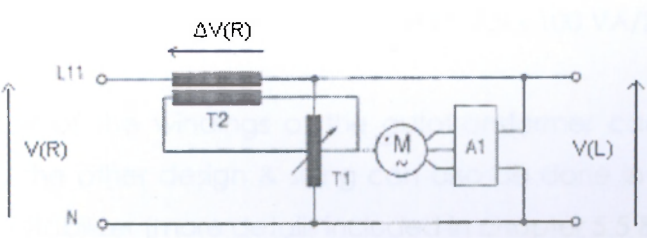


Fig 5.11: Schematic diagram of Servo motor system (related to voltage correction)

(A1 - Control unit, M - Servo drive, T1 - Variable autotransformer, T2 - Booster transformer, V_R - resultant voltage seen by the load at PCC, V_L – Corrected voltage to the load at the stabilizer output)

The T2 Booster transformer will adjust the V_R by changing the topping points of the T1 variable transformer in order to correct and keep stable the load voltage V_L.

The resultant voltage at the load can be represented as per equation (10) bellow.

$V_L = V_R + \Delta V_R$ .... (10)

Design & sizing of the stabilizer system including the autotransformer, servo motor and the control system to suite the Telecom site requirement can be summarized as follows. The following example calculation can be given.

Input voltage	= 140 – 240V (ΔV_R = 100V)
Output voltage	= 230V accuracy 1.5%
Power capacity	= 7.5 KVA
Adjusted speed	=10V/sec

Select Autotransformer of capacity 7.5KVA, 1ph with input voltage range 140-240V, turns 200 and the servo motor selected as 50W, 12V DC with speed suitable for 10V/sec movements by controlled shaft displacement of the rolling brushed on the winding turns.

The cross section of the windings can be assumed by the followings manner.

ΔV_R (100V) = R (winding) x I (winding)

R = ρL / A where p – Cu resistivity, L –length, A – cross section of winging.

R = ΔV_R (100V) / I (winding) where I = 7.5 x 100 VA/230V = 32.6A

The A & R of the windings of the autotransformer can be sized as above. In addition, the other design & sizing can also be done in the same simple way to order the stabilizer (more details included in chapter 5.5 & 5.6).

5.12.3 Power Quality disturbances

PQ problems can originates in, the supply system, the customer's equipments or a neighboring installation and propagate via the supply.

Problems in Supply System can be Lightning strikes (Voltage transients or Failure of equipment) or Line capacitor Switching (Oscillatory transients), or Faults on feeders (Voltage variations), or Asymmetrical nature of transmission lines and transformers (Voltage unbalance).

Problems Originated by Customer's Equipments can be Sudden connection or disconnection of large loads which results Voltage variations, Unequal distribution ot single phase loads, Voltage unbalance, Cyclic loads, Light flicker, Power electronics loads, Harmonic distortions or High frequency noise.

There are three different types of PQ disturbances;

1. Frequency events (Change of frequency outside the acceptable range)
2. Voltage events (magnitude is outside the range)
3. Waveform events (shape of the waveform is unacceptable).

Frequency of the power system is established by the rotational speed of the power station generators. It is very rare that this frequency is varied significantly.

5.12.4 Voltage fluctuations

Voltage fluctuations defined as repetitive or random variations in the magnitude of the supply voltage. The magnitudes of these variations do not usually exceed 10% of the nominal supply voltage. The characteristics of voltage fluctuations depend on, load type and size and the power system capacity.

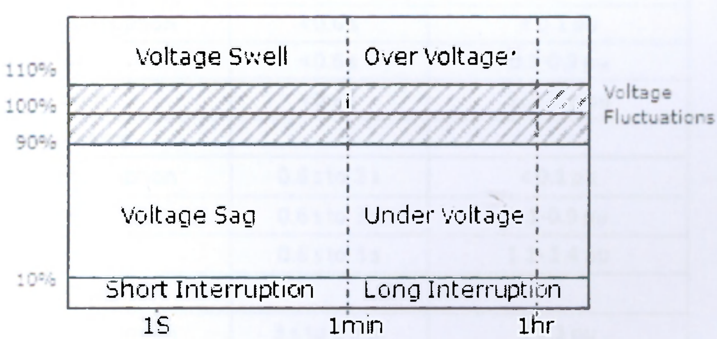


Fig 5.18: Characteristics of voltage fluctuations

The voltage waveform exhibits variations in magnitude due to the fluctuating nature or intermittent operation of connected loads. Two important parameters to voltage fluctuations are Frequency of fluctuation and Magnitude of fluctuation.

Voltage fluctuations are caused when;

1. Loads draw currents having significant sudden or periodic variations.
2. The fluctuating current drawn from the supply causes additional voltage drops in the power system leading to fluctuations in the supply voltage.
3. Loads that exhibit continuous rapid variations are the most likely cause of voltage fluctuations. Examples are Arc furnaces, Arc welders, Installations with frequent motor starts (air conditioner units, fans), Motor drives with cyclic operation (mine hoists, rolling mills) and Equipment with excessive motor speed changes (wood chippers, car shredders)

Voltage variations can be divided in to several categories; Transients, Short term variations, Long term variations, Voltage unbalance, Continuous or random fluctuations/ Flicker, Interruptions (Supply is loss completely) and Neutral to ground voltage variations (due to poor earthing practice).

The Short Duration Variations is less than 1 minute and the classifications can be tabulated as follows.

Category	Duration	Voltage Magnitude
Instantaneous		
Interruption	<0.6 s	< 0.1 pu
Sag	<0.6 s	0.1-0.9 pu
Swell	<0.6 s	1.1- 1.8 pu
Momentary		
Interruption	0.6 s to 3 s	< 0.1 pu
Sag	0.6 s to 3 s	0.1-0.9 pu
Swell	0.6 s to 3 s	1.1- 1.4 pu
Temporary		
Interruption	3 s to 1 min	< 0.1 pu
Sag	3 s to 1 min	0.1-0.9 pu
Swell	3 s to 1 min	1.1- 1.2 pu

Table 5.12: Short Duration Voltage Variation categories

The Long-term variation is the rms value variation at power frequency for duration more than 1 minute. The Variations are called as;

1. Under voltages – Voltage less than 90% of nominal voltage
2. Over voltages - Voltage greater than 110% of nominal voltage
3. Sustained Interruption

Under voltage is decrease in rms value less than 90% of nominal value at the power frequency for duration longer than 1 minute. The Causes can be Switch on large loads, Switch off capacitor banks, Malfunction of voltage regulation equipments or Over loading circuits.

Over Voltage is an increase in rms value greater than 110% of nominal value at power frequency for duration longer than 1 minute. The Causes can be Switch off large loads, Energizing capacitor banks, Incorrect tap settings of transformers or When the system is week in voltage regulation and voltage control is inadequate.

Sustained Interruption exists when the supply voltage has been zero for a period of time exceeds 1 minute. Normally these are permanent and human intervention is required to resume power. The Causes can be System fault causing "brown out" or "black out".

The Wave form events result in distortion of normal sinusoidal wave shape of the voltage. There are several categories of waveform events, such as; Harmonics, Inter harmonics, Notches, Noises & Transients.

The Institute of Electrical and Electronics Engineers (IEEE) has set recommended limits on both current and voltage distortion in IEEE 519-1992.

Voltage distortion limits at low-voltage bus is as follows.

Application class	THD (voltage)
Special system	3 %
General system	5 %
Dedicated system	10 %

The maximum harmonic current distortion as per the IEEE 519 on Individual harmonic number (odd harmonics) is as follows.

I_{sc}/I_L	<11	11<h<17	17<h<23	23<h<35	TDD
<20	4.0	2.0	1.5	0.6	5.0
20-50	7.0	3.5	2.5	1.0	8.0
50-100	10.0	4.5	4.0	1.5	12.0
100-1000	12.0	5.5	5.0	2.0	15.0
>1000	15.0	7.0	6.0	2.5	20.0

Table 5.13: Maximum harmonic current distortion as per the IEEE 519

(I_{SC}: Maximum short-circuits current at the Point of Common Coupling (PCC), I_L: Maximum demand load current (fundamental) at the PCC).

Voltage fluctuations in power systems also cause a number of harmful technical effects resulting in disruption to production processes with substantial costs. Light Flicker results due to voltage fluctuations. In the Electric machines, Change in torque and In the worst case, excessive vibration, reducing mechanical strength and shortening the motor service life, will results due to voltage fluctuations. In the Static rectifiers, generation of non-characteristic harmonics and inter-harmonics can be seen. The sensitivity to voltage fluctuations is a function of the frequency and it is also dependent on the voltage level of the lighting.

Voltage sags on the supply system have a significant retained voltage, So that energy is still available. For these equipments, no energy storage mechanism is required and relies on generating full voltage from the energy still available at reduced voltage during the dip and they are known as "Automatic Voltage Stabilizes". The main types of Automatic Voltage Stabilizers available are Electro-mechanical, Electronic step regulators, Electronic voltage stabilizer (EVS) and Ferro-resonant or constant voltage transformer (CVT).

The Voltage Sag is mainly affect to the telecom equipment operations and also effects to Power Electronics & Process control Equipments and, Loss of production, Damage product & Damage equipments can be seen.

There are two sources of voltage sags, External on the utility's lines up to the facility or Internal within the facility. Utilities continuously strive to provide the most reliable and consistent electric power possible. In most cases, the majority of sags are generated inside a facility.

5.12.5 Managing PQ Problems

Control of PQ problems involves cooperation between network operator, customer and equipment manufacturer. Most PQ problems can be solved within the plant itself. Careful identification of the source of PQ problem is essential.

General Guide to Manage PQ Problems can be listed as follows.

1. Identify the weaknesses in the power supply (Monitoring the supply),
2. Identify the critical components and their susceptibility to power quality events,
3. Specify all new critical equipments to withstand worse case supply conditions,
4. Seek assurance from equipment manufactures that the equipment meets PQ specifications,
5. Ensure that the equipment purchased dose not cause further degradation of PQ.

The effects of voltage fluctuations depend on their amplitude, which influenced by the characteristics of the power system, and Rate of their occurrence, which determined by the technological process, i.e. type of load and character of its operation. Usually, mitigation measures are targeted at actions focused on limiting the amplitude of the voltage fluctuations.

The Plant Level Options can be characterized as follows.

In the Arc furnace, it is possible to incorporate a series reactor (or variable saturation), proper functioning of the electrode control system, segregation and preliminary heating of charge, etc. In the Welding plant, it is possible to supply the plant from a dedicated transformer, connecting single-phase welders to the three-phase network for balanced load distribution between phases, and also by connecting single phase welding machines to different phases from those powering lighting equipment, etc. In the Adjustable speed drives, it is possible to use of soft-start devices.

The Utility Level Options can be characterized as follows.

Increasing the short circuit power (with respect to the load power) at the point of coupling to which a fluctuating load is connected. It is possible to connect the load at a higher nominal voltage level or supplying this category of loads from dedicated lines or separating supplies to fluctuating loads from steady loads, or increasing the rated power of the transformer supplying the fluctuating load, or installing series capacitors. Reducing the changes of reactive power in the supply system by; installing dynamic compensators/stabilizers.

Negotiate with the supply company for a lower impedance connection, Reduce the number of line Faults by Use UG cables instead of OH lines & Wave leaves clearing and Reduce the fault clearing time are some of the System Improvements.

5.12.6 Power Quality Standards

International Standards Groups mainly includes the IEC, EN, ANSI, IEEE, NEMA standards and include standards for PQ.

1. International Electro technical Commission (IEC) Industry group that writes and distributes standards for electrical products and components in general.
2. European Norm (EN) or European Standard, which carries with it the obligation to be implemented at national level and having priority over any conflicting national standard CIGRE (SC 36).
3. American National Standard Institute (ANSI) ANSI facilitates the development of American National Standards (ANS) by accrediting the procedures of standards developing organizations.
4. Institute of Electrical and Electronics Engineers (IEEE) , The Institute of Electrical and Electronics Engineers Standards Association (IEEE-SA) is the leading developer of global industry standards in a broad-range of industries, including the Power and Energy.

5. National Electrical Manufacturers Association (NEMA) , National Institutes of Science and Technology (NIST), National Electrical Code, NFPA 70, National Fire Protection Association(NFPA), Underwriters Laboratories (UL).

The following IEEE standards include the standards relevant for the PQ.

IEEE 1159 (Monitoring Electric Power Quality), IEEE 1159.1 (Guide For Recorder and Data Acquisition Requirements), IEEE 1159.2 (Power Quality Event Characterization), IEEE 1159.3 (Data File Format for Power Quality Data Interchange), IEEE 1564 (Voltage Sag Indices), IEEE 1346 (Power System Compatibility with Process Equipment), IEEE 1100 (Power and Grounding Electronic Equipment, IEEE 1433 (Power Quality Definitions), IEEE 1453 (Voltage flicker), IEEE 519 (Harmonic Control in Electrical Power Systems), IEEE 519A (Guide for Applying Harmonic Limits on Power Systems), IEEE 446 (Emergency and standby power), IEEE 1409 (Distribution Custom Power), IEEE 1547 (Distributed Resources and Electric Power Systems Interconnection), etc

As per European Standard, EN 50160, the purpose of the standard is to direct in the proper monitoring and data interpretation of electromagnetic phenomena that cause power quality problems. The categories and their descriptions are important in order to be able to classify measurement results.

Supply voltage phenomenon	Acceptable limits	Measurement Interval	Monitoring Period	Acceptance Percentage
Grid frequency	49.5Hz to 50.5Hz 47Hz to 52Hz	10 s	1 Week	95% 100%
Slow voltage changes	230V ± 10%	10 min	1 Week	95%
Voltage Sags or Dips (≤1min)	10 to 1000 times per year (under 85% of nominal)	10 ms	1 Year	100%
Short Interruptions (≤ 3min)	10 to 100 times per year (under 1% of nominal)	10 ms	1 Year	100%
Accidental long interruptions (> 3min)	10 to 50 times per year (under 1% of nominal)	10 ms	1 Year	100%
Temporary over-voltages (line-to-ground)	Mostly < 1.5 kV	10 ms	N/A	100%
Transient over-voltages (line-to-ground)	Mostly < 6kV	N/A	N/A	100%
Voltage unbalance	Mostly 2% but occasionally 3%	10 min	1 Week	95%
Harmonic Voltages	8% Total Harmonic Distortion (THD)	10 min	1 Week	95%

Table 5.14: Supply voltage measurement as per European Standard, EN 50160

RESULTS AND ANALYSIS

6.1 Overview of Outcomes

The following outcomes were expected in this research project as mentioned initially in the section 1.5, under "Expected Outcomes" and can be categorized as direct financial benefits, operational overhead reductions & technical benefits.

The results can be obtained by referring various reporting sources within the company (Lanka Bell Limited) and the recorded improvements can be identified. The comparison of those results before & after the implementation can be done by referring the information sources mentioned under each category of outcomes in the following tables.

6.1.1 Direct Financial Benefits

Category of Outcome/ Benefit	Information Source
Recover the revenue from network up time	"CDMA Outage Report" of Network Operation Center
Customer satisfaction due to unbreakable service	"Customer Complain Report" of Customer Care Department
Reduction of expenses for failure recovery due to power problems	"Operation Overhead Report" of Maintenance Department
Minimum part replacements with reduction of equipment failures	"Maintenance Spare Part expense Report" of Warehouse
Other financial benefits related to network revenue	"Monthly Revenue Report" of Finance Department

Table 6.1: Main categories & Information Sources of Direct Financial Benefits

6.1.2 Operational Overhead Reductions

Category of Outcome/ Benefit	Information Source
Minimum use of Diesel Generator for the operation	"Generator Diesel Expenses Report" of Transport Department
Minimum attention & visits for day to day failure recoveries	"Cluster OPA Expense Report" of Clusters
Low routine maintenance visits with reduction of maintenance cost	"Preventive Maintenance expense Report" of Maintenance Department

Table 6.2: Main categories & Information Sources of OPEX Reductions

6.1.3 Technical Benefits

Category of Outcome/ Benefit	Information Source
Improve the efficiency of power to equipments, hence low electricity cost	"BTS Electricity Cost Report" of Maintenance Department
Extending the equipment operational lifetime with quality power & reduce interruptions	"Maintenance Spare Part expense Report" of Warehouse
Maintain the room temperature in the recommended range for healthy operation	"High Temperature Alarm Report" of Network Operation Center
Reduce the losses in the equipments in operation with quality power	"BTS Electricity Cost Report" of Maintenance Department
Reduced environmental & power surges in to the room and improved protection	"Maintenance Spare Part expense Report" of Warehouse

Table 6.3: Main categories & Information Sources of Technical Benefits

The expected outcomes can be quantified by referring the above information sources generate by each of the departments involve on the Network Operations in Lanka Bell Limited.

The reports on each category were obtained for last 4 months starting from August, up to November 2008. At the moment, the research implementation was completed at 19 sites (13% completion of total, and most of them are backbone sites) in the first stage and this was commissioned & affected from November 2008 onward.

The progress of the implementation up to November 2008 is as follows. The detailed implementation schedule was given in section 5.2, table 5.1 previously.

Stage	No of Sites	Target Scheduled	Progress
Stage 1	19	by Nov. 2008	Done
Stage 2	124	by May 2009	Not yet started

Hence, the information of last 3 months, August, September & October can be compared with the same of November in order to get the improvements in the mentioned areas and this is 13% of the scope of this project.

The graphical representations of the above results in each category can be shown as follows and the improvements can be directly identified.

6.2 Reduction of the Network Outage Time

The total network comprise of 360 Base station sites and all are interconnected through back bone sites (around 40 island wide and selected 19 sites came under this 1st stage implementation) to make to network expanded from point to point.

Any outage especially in back bone site will affect to all the connected sites at the next part of the network, and service will be interrupted at all the sites.

The "CDMA Outage Report" generated by the Network Operation Center (NOC) will gives the outage time of each month at all the Base stations with the reasons on such failures.

The outage summary of last 4 months can be tabulated as follows.

Problem Category	August		September		October		November	
	Sites	Duration (Hrs)	Sites	Duration (Hrs)	Sites	Duration (Hrs)	Sites	Duration (Hrs)
Power	71	334	82	310	95	293	64	246
Generator	21	36	18	82	16	95	3	15
Link	69	436	82	487	73	461	95	381
Radio	82	586	63	452	79	536	58	483
Planned outage	35	19	28	31	36	22	82	29

Table 6.4: Summary of network outages in last 4 months

The Graphical representation of the above summary is as follows.

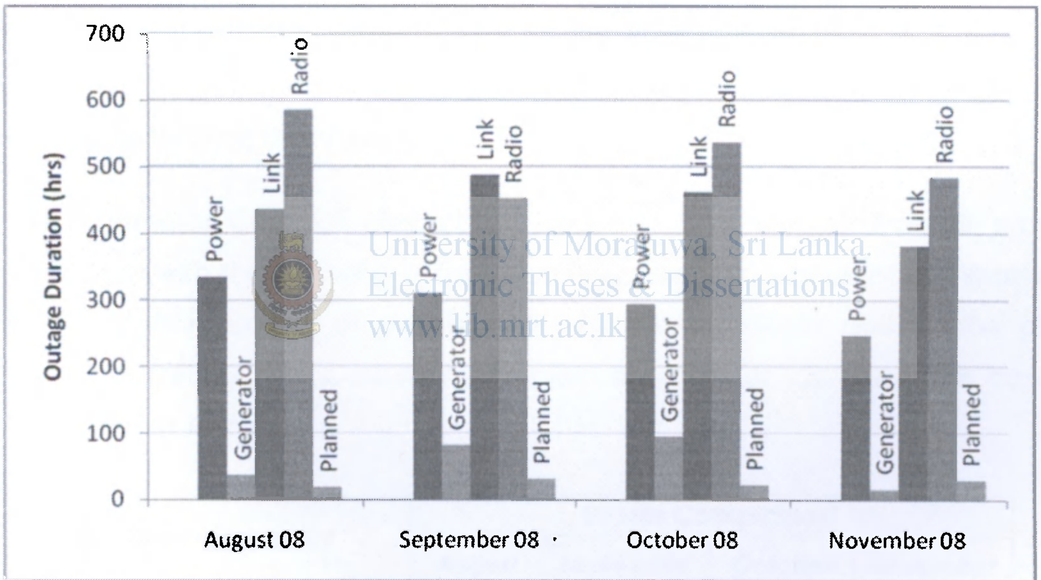


Fig 6.1: Graphical representation of network outages in last 4 months

The above graph clearly shown a considerable reduction of downtime especially on Power, Generator & Radio related problems which are directly related with power quality problems of the relevant base station sites. As the initial sites selected are backbone sites, downtime reduction is help to keep the next part of the network active. Hence the saving on many ways due to "network outage reduction" as mentioned in the table 6.1, 6.2 & 6.3, are directly outcomes of this project.

The available data is of the total network, and will vary on many other factors such as fault identification errors, technical errors in the alarm signals, planed outages, cyclic variations of outages due to non technical reason, etc. Hence, considerable error on the above data is expected when we relate the above changes to this scope at this stage and may not provide the correct picture.

However, the main objective is to present some quantification to prove the benefits of this project and the rest of the results can be seen clearly (with recorded results over several months) after completion of 124 sites in the 2nd stage before May 2009.

6.3 Reduction of the Customer Complains

The 24 hrs x 365 days operating "Customer care unit" with over 100 of agents are always with the clear understanding on the Customer related problems of the Network and most of the useful information can be obtained by referring the reports generating by this department.

The "Customer Complain Report" of Customer Care Department will provide complains with the following technical categories and number of complains will represent the number of events faced by the customers due to the given technical failures. The Customer Complain summary of last 4 months can be tabulated as follows.

Complain Category	**Events Complained**			
	August	***September***	***October***	***November***
Billing Errors/ Tariff Clarifications	26,463	36,458	21,845	31,257
Phone unit problems/ Clarifications on features	33,568	37,459	41,212	29,458
No Coverage/ low signal Problems	8,785	10,879	9,876	7,298
Noise in voice/ Call unclear complains	12,856	14,576	16,268	11,892
Other Complains	51,425	48,251	38,256	33,260

Table 6.5: Summary of Customer Complains in last 4 months

The Graphical representation of the above summary is as follows.

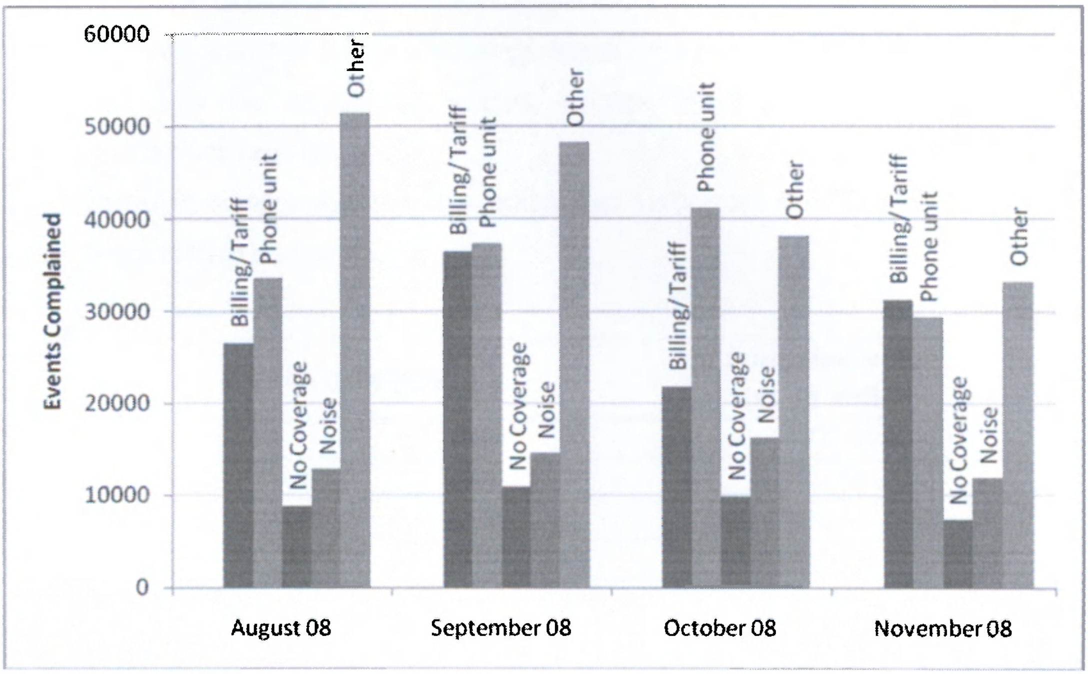


Fig 6.2: Graphical representation of Customer Complains in last 4 months

The above graph shown a significant reduction of customer complains especially on Coverage & noise issues which are related with power quality of the base station served to the respective customer. Hence, the reduction of complains will indicate the improvement of customer satisfaction & quality of the service in the month of November 2008.

The available records of the total customer base can not be filtered by each site or by network patterns. In addition, those records will vary on many other factors also. Hence, the above reduction may not justifiable to relate directly to the scope at this stage but more clear result can be obtained after completion of 124 sites in the 2nd stage.

However, as this project already could reduce the downtime of 19 of backbone sites out of 40 in the network, we can believe on a justifiable relation with the above reduction of customer complains as improvements of the network up time.

6.4 Reduction of the Operational Overhead

The operation overhead of the Maintenance Department (Lanka Bell Limited) can be categorized in to the followings areas and the expenses will not allow to increase than the budgeted values, except in special cases with higher management approvals.

The overhead categories with the budgeted values for the financial year 2008 can be tabulated as follows.

OPEX category	Budgeted value (Rs. In Million)
Electricity	450 M
Spares & Consumables	42 M
Diesel for generator operation	35 M
Transport	3.8 M
Staff expenses (Meal, OT, on call, OPA, Logins)	1.8 M
Plant, equipment & tool repairs & replacements	1.6 M
Service Contracts	7.1 M
Equipment Rental	0.8 M
Office expenses (mobile, stationery, training, etc)	0.4 M
Miscellaneous	0.2 M

Table 6.6: Summary of the budgeted OPEX categories for maintenance

The actual expenses under the above operational overhead can be obtained from the following reports.

1. "Operation Overhead Report" of Maintenance Department,
2. "BTS Electricity Cost Report" of Maintenance Department,
3. "Maintenance Spare Part expense Report" of Warehouse,
4. "Generator Diesel Expenses Report" of Transport Department
5. "Preventive Maintenance expense Report" of Maintenance Department
6. "Cluster OPA Expense Report" of Clusters

The Operational expenses related to base stations maintenance (except of main administration & switching centers in Colombo) for last 4 months can be tabulated as follows.

OPEX Category	Actual Expenses (Rs. ,000)			
	August	***September***	***October***	***November***
Electricity	12,635	13,358	12,226	12,287
Spares & Consumables	720	635	810	705
Diesel for generator operation	4,360	3,250	4,128	2,910
Transport	316	425	367	298
Staff expenses (Meal, over time, on call, OPA, Logins)	156	178	127	95
Plant, equipment & tool repairs & replacements	33	47	28	32
Service Contracts	345	352	362	325
Equipment Rental	12	15	14	6
Office expenses (mobile, stationery, training, etc)	52	58	62	48
Miscellaneous	8	9	7	8

Table 6.7: Summary of the actual OPEX in last 4 months

The Graphical representation of the main OPEX items is as follows.

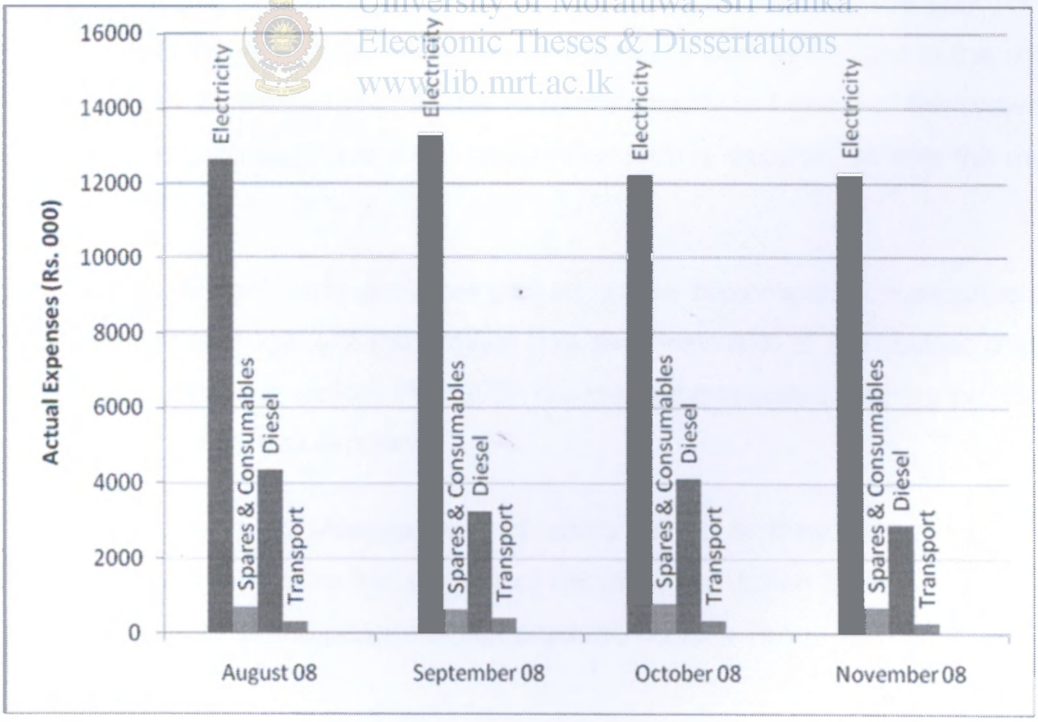


Fig 6.3: Graphical representation of main actual OPEX in last 4 months

The above graph shown a significant reduction of OPEX especially on Electricity, Spare, Diesel and Transport which are related with power quality of the base station sites. As the initial 19 sites selected are highest Generator running sites due to huge voltage drops, the above OPEX reductions are directly outcomes of this project and further reduction is possible after completion of 124 sites in the 2nd stage before May 2009.

As a summary, it is already shown that, the research project implemented at 19 main backbone sites gave significant benefits in terms of OPEX & CAPEX reductions to the company.

This is very important as, the selected 19 sites in stage 1 are very critical sites having many interconnections of the network and reduction of outages is very important and the uptime of those sites are considerable revenue source to the company.

It is also important to note that, the data shown above are having only just a month of data after implementing this project. Hence, the cyclic variations and any other factors continuing from past 3 months can affect to the variations of the figures in the 4th month. Therefore, any benefit/ cost reductions in the month of November 2008 can not justifiable to relate directly as benefit of this project at this stage as data available is not enough for such a decision, as only this month data in hand.

Hence, we can get more accurate picture on the implementation progress after completing the stage 2 of this project (124 sites, next 87% of the scope) and our target is to complete before May 2009, assuming the required funding possible to be acquired from the company.

We must thank to the Management of Lanka Bell Ltd as they already grant over Rs.1,600,00.00 funding for the stage 1 of this implementation after accepting the possible benefits of this project which produce more revenue with in a very short payback period.

FINANCIAL FESIBILITY ANALYSIS

7.1 Overview

The financial feasibility of this project will discuss on the capital investment for this voltage correction system including the associate modifications at each sites categorized under RBS Models, over the savings on Generator operation cost reductions and savings on uninterrupted customer service from the respective base station sites, in case by case basic. As the outages of such sites are very critical & major revenue loss to the company, expenditures to keep the extended up time are justifiable and having short pay back period.

The cost considerations can be listed as follows.

Expenditures

1. Cost for the initial testing & information surveys.
2. Cost for the modifications & additions to the power related equipments.
3. Cost for the purchase of voltage stabilizers which were locally designed & fabricated, as per the customer specifications & requirements.
4. Cost for further modifications, improvements & advancements of the systems.

Savings

1. Reduction of Generator operation cost.
2. Reduction of revenue losses due to customer service outages.
3. Reduction of expenditures for repairs of equipment damaged due to low voltage.
4. Reduction of energy losses on low voltage operation and savings due to improved efficiency of the system and associated operations.

The detailed calculations of the above cost considerations are discussed from next page onward with the assumptions taken.

7.2 Cost Calculation for Generator Operation at Telecom Base Station

7.2.1 Diesel Generator as Back up Power Source

Statistics (Assumptions for Cost calculation)		
	Rate	*Unit*
General Details		
Capacity of the Generator	12.5	KVA
Purchased Price (Capital)	9,600	US$
Distance to the site from Colombo	150	Kms
Distance to the site from Cluster	40	Kms
Commercial Power Availability (Yes/ No)	Yes	
Operational Details		
BTS Loading (Power)	60	% of full load
Generator Operating Hours per Day (Avg.)	5	Hrs/ Day @ CEB Peak
Number of Preventive Maintenance	4	Jobs/ Year
Recommended Lifetime of the Generator	16,000	Hrs
Residual Values of Generator	10	% of capital
Generator Fuel Consumption	3.2	Liters/ Hr @ 80% Load
Generator Output Power (Amp 3Ph)	18	Amp/ Phase
Generator Re-fuel Level (Diesel Top-up)	45	Liters
Financial Details		
Site Rental charges	15,000	Rs/ Month
Transport cost	25.00	Rs/ Km
Portal Charges	500	Rs/ Can
Professional expenses	5,000	Rs/ Visit
Salary of Diesel Technician	450	Rs/ Day
Salary of Generator Technician	15,000	Rs/ Month
Cost for OPA (Foods & Login)	600	Rs/ Day
Price of Diesel	120.00	Rs/ Liter
Price of Consumables (Lube Oil, Oil/ Fuel Filters, Battery Water, etc)	4,240	Rs/ Service
Mini Overhaul cost (Material + Labor)	350,000	Rs/ Job
Major Overhaul cost (Material + Labor)	650,000	Rs/ Job
Selling Markup of the Gen power	30	% of actual

Cost Calculation (Generator Operation)				
	Qty	***Unit***	***Cost (Rs.)***	
Capital & Initial Expenditures				
Generator Depreciation	1	Life	Each Month	8,910.00
Site Rental charges (Plinth space)	0.05	Rental %	Each Month	750.00
Installation & Commissioning				
Transport (Up & Down)	300	Kms	Initial	7,500.00
Labor (Technician)	2	Man Days	Initial	1,200.00
Professional expenses	1	Visits	Initial	5,000.00
Foods & Login	2	Man Days	Initial	1,200.00
Periodical Service Expenditures				
Preventive Service				
Consumables	4	Service	Each Year	16,960.00
Transport (Up & Down)	80	Kms	Each Year	2,000.00
Labor (Technician)	2	Man Days	Each Year	1,200.00
Foods & Login	2	Man Days	Each Year	1,200.00
Overhauling Cost				
Mini Overhaul at each 5,000 hrs	2	Life	Each Year	383.56
Diesel Expenditures				
Diesel	2.4	Liters	Each Hour	288.00
Transport (Up & Down)	80	Kms	Each Visit	2,000.00
Portal Charges	2	Cans (20L)	Each Visit	1,125.00
Labor (Diesel Tech.)	0.25	Man Days	Each Visit	112.50
Total Cost on the Gen Operation				
Fixed Cost (Per Month)		46,145	Rs/ Month	
Variable Cost (Per Hour on BTS load)		288	Rs/ Gen Hr	
Final Value for the Operator (per Month)		**89,345**	Rs/ Month	plus VAT
(Fixed cost + Unit consumed x Rate)				

7.2.2 Diesel Generator as Main Power Source

Statistics (Assumptions for Cost calculation)		
	Rate	*Unit*
General Details		
Capacity of the Generator	12.5	KVA
Purchased Price (Capital)	9,600	US$
Distance to the site from Colombo	150	Kms
Distance to the site from Cluster	40	Kms
Commercial Power Availability (Yes/ No)		No
Operational Details		
BTS Loading (Power)	60	% of full load
Generator Operating Hours per Day (Avg.)	24	Hrs/ Day @ CEB Peak
Number of Preventive Maintenance	4	Jobs/ Year
Recommended Lifetime of the Generator	16,000	Hrs
Residual Values of Generator	10	% of capital
Generator Fuel Consumption	3.2	Liters/ Hr @ 80% Load
Generator Output Power (Amp 3Ph)	18	Amp/ Phase
Generator Re-fuel Level (Diesel Top-up)	45	Liters
Financial Details		
Site Rental charges	15,000	Rs/ Month
Transport cost	25.00	Rs/ Km
Portal Charges	500	Rs/ Can
Professional expenses	5,000	Rs/ Visit
Salary of Diesel Technician	450	Rs/ Day
Salary of Generator Technician	15,000	Rs/ Month
Cost for OPA (Foods & Login)	600	Rs/ Day
Price of Diesel	120.00	Rs/ Liter
Price of Consumables (Lube Oil, Oil/ Fuel Filters, Battery Water, etc)	4,240	Rs/ Service
Mini Overhaul cost (Material + Labor)	350,000	Rs/ Job
Major Overhaul cost (Material + Labor)	650,000	Rs/ Job
Selling Markup of the Gen power	30	% of actual

Cost Calculation (Generator Operation)				
	Qty	***Unit***	***Cost (Rs.)***	
Capital & Initial Expenditures				
Generator Depreciation	1	Life	Each Month	42,768.00
Site Rental charges (Plinth space)	0.05	Rental %	Each Month	750.00
Installation & Commissioning				
Transport (Up & Down)	300	Kms	Initial	7,500.00
Labor (Technician)	2	Man Days	Initial	1,200.00
Professional expenses	1	Visits	Initial	5,000.00
Foods & Login	2	Man Days	Initial	1,200.00
Periodical Service Expenditures				
Preventive Service				
Consumables	4	Service	Each Year	16,960.00
Transport (Up & Down)	80	Kms	Each Year	2,000.00
Labor (Technician)	2	Man Days	Each Year	1,200.00
Foods & Login	2	Man Days	Each Year	1,200.00
Overhauling Cost				
Mini Overhaul at each 5,000 hrs	2	Life	Each Year	79.91
Diesel Expenditures				
Diesel	2.4	Liters	Each Hour	288.00
Transport (Up & Down)	80	Kms	Each Visit	2,000.00
Portal Charges	2	Cans (20L)	Each Visit	1,125.00
Labor (Diesel Tech.)	0.25	Man Days	Each Visit	112.50
Total Cost on the Gen Operation				
Fixed Cost (Per Month)		211,735	Rs/ Month	
*Variable Cost (**Per Hour** on BTS **load**)*		288	Rs/ Gen Hr	
Final Value for the Operator (per Month)		**419,095**	Rs/ Month	plus VAT
(Fixed cost + Unit consumed x Rate)				

7.2.3 Summary of the Generator operational cost vs. running hours

The above is for the operation cost of Generator as backup power during normal light peak voltage reduction period (as per CEB load curve, the highest loading observed and the power will be dropped during 6 – 8am and 6 – 9pm with the light loading) and as full 24hr running at none CEB power available sites.

The intermediate values are calculated and tabulated as follows.

Gen running hours (hrs)	Operational Fixed cost (Rs)	Operational variable cost (Rs)	Total operational cost per Month (Rs)
1	11,406	8,640	20,046
2	20,043	17,280	37,323
3	28,733	25,920	54,653
4	37,436	34,560	71,996
5	46,145	43,200	89,345
6	54,856	51,840	106,696
7	63,569	60,480	124,049
8	72,283	69,120	141,403
9	80,997	77,760	158,757
10	89,712	86,400	176,112
11	98,427	95,040	193,467
12	107,143	103,680	210,823
13	115,858	112,320	228,178
14	124,574	120,960	245,534
15	133,290	129,600	262,890
16	142,006	138,240	280,246
17	150,722	146,880	297,602
18	159,438	155,520	314,958
19	168,154	164,160	332,314
20	176,870	172,800	349,670
21	185,586	181,440	367,026
22	194,303	190,080	384,383
23	203,019	198,720	401,739
24	211,735	207,360	419,095

Table 7.1: Generator operation cost vs. running hours at radio base station site.

7.3 Analysis of Traffic loading on standard Telecom Base Station site

The calculation of the revenue loss during the base station downtime can be calculated for different RBS Models and the areas considered can be described below.

The customer loading on the base station site will depend on the time period of the day and some of the collected BTS Traffic curves (specially considering the 19 under voltage sites) can be shown as follows. The Y axis is Traffic in "Erlang" which is the measuring unit on customers loading (Traffic) per line average in one hour period. It can roughly assume number of call hours handled during the given one minutes period (1 Erlang = 60 min of usage).

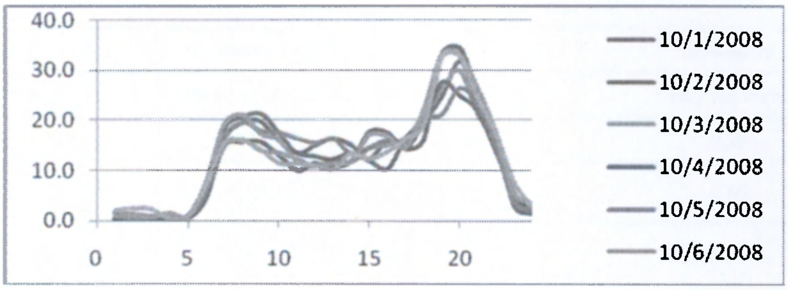


Fig 7.1: Traffic curve (in Erlang) of Badalkumbura RBS site for one week period

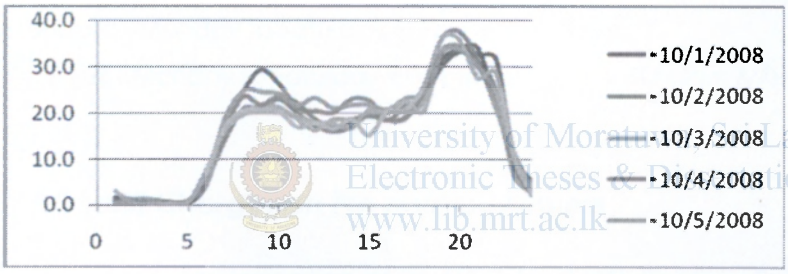


Fig 7.2: Traffic curve (in Erlang) of Hatharaliyadda RBS site for one week period

However, most of the curves are in same shape and this is mainly due to the call charges (time of day tariff) in time slot basis.

In addition, average set up time (ringing time before call connects) is 30% of the total call in Erlang curve and hence only 70% will applicable for the effective revenue calculations. The Average holding time (call time) is 1.8 Minutes (33 calls per hour) and can be used for the calculations.

7.4 Analysis of Tariff packages applicable for the customers

In order to calculate the revenue earned, the common few tariffs can be considered as flows, which covers post paid, pre paid and IDD customers.

7.4.1 Tariff Charges on post paid customers

Lanka Bell to Lanka Bell			
	Peak	Standard	Economy
	* Rs / Per Minute	* Rs / Per Minute	* Rs / Per Minute
Local	1.50	0.75	0.10
National	3.75	1.60	0.35

Lanka Bell to Other Operator			
	Peak	Standard	Economy
	* Rs / Per Minute	* Rs / Per Minute	* Rs / Per Minute
Local	1.75	1.00	0.20
National	4.40	2.00	0.60

Table 7.2: Tariff Charges on post paid customers.

Monthly Rental Rs.320.00, Start up fee Rs.2.95 per call and Incoming totally free.

Peak - Monday to Saturday 7.00 am to 6.00 pm.

Standard - Monday to Saturday 6.00 pm to 9.00 pm.

Off Peak - Monday to Saturday 9.00 pm to 7.00 am. Sundays & Public Holidays

7.4.2 Tariff Charges on Pre paid customers

Available In denomination of Rs. 5000, Rs. 2,500, Rs.1000, Rs.500 and Rs.300, Bell Tell also offers affordable call rates and per minute charges as follows.

Lanka Bell to Lanka Bell		
	Standard	Economy
	* Rs / Per Minute	* Rs / Per Minute
Local	2.90	1.90
National	3.90	2.90
Lanka Bell to Other Operators		
	Standard	Economy
	* Rs / Per Minute	* Rs / Per Minute
Local	2.90	1.90
National	3.90	2.90

Table 7.3: Tariff Charges on pre paid customers.

7.4.3 Tariff Charges on IDD customers

Country	To Fixed Lines	To Mobiles
AUSTRALIA	8	20
BANGLADESH	8	11
CANADA	8	8
CHINA	8	11
FRANCE	8	20
HONG KONG	8	11
INDIA	12	25
INDONESIA	8	20
ITALY	8	20
JAPAN	8	20
KOREA SOUTH	8	11
KUWAIT	10	25
MALDIVE IS	25	30
NEPAL	25	35
NEW ZEALAND	8	20
QATAR	25	35
SINGAPORE	8	11
SOUTH AFRICA	8	20
TAIWAN	8	11
THAILAND	8	11
UNITED KINGDOM	8	20
USA	8	8
Average	**11**	**18**

Table 7.4: Tariff Charges on IDD customers.

7.4.4 Summary of Revenue calculation on call charges for a period of 24hrs

Generally assuming the calls handled by the RBS in the following Tariff basis, the revenue can be averagely tabulated for the hour basis from the above data collected.

Percentage of Post paid customers (local calls only) – 70 %

Percentage of pre paid customers (local calls only) – 27 %

Percentage of IDD customers (to fixed lines) – 3 %

The revenue on each time slot can be calculated with the above assumptions and this will reflect the incoming from standard base station site.

Example:

Unit call charge at 20.00 = [(33 x 2.95)+(0.2x 0.7+2.9x 0.27+11x 0.03)x 60]/60 = Rs. 2.88/ min

Revenue = Rs. 2.88/ min x 35 Erlang x 60 x 70% = Rs. 4,227.00

The same can be calculated for the other time bands and tabulated as follows.

Time slot of Day	Customer Loading	Average post paid charge (Rs/min)	Average pre paid charge (Rs/min)	Average IDD charge (Rs/min)	Unit call charge (Rs/min)	Revenue (Rs/hour)
00.00-01.00	1	1	2.9	11	3.44	144
01.00-04.00	2	1	2.9	11	3.44	289
04.00-08.00	20	1.75	2.9	11	3.96	3,327
08.00-12.00	10	1.75	2.9	11	3.96	1,663
12.00-16.00	15	1.75	2.9	11	3.96	2,495
16.00-20.00	35	0.2	2.9	11	2.88	4,227
20.00-24.00	3	1	2.9	11	3.44	433

Table 7.5: Revenue calculation on call charges for a period of 24 hours

7.5 Revenue saving per day on each RBS Model

The voltage stabilizing unit will help to maintain the customer operation without any outage and hence the saving of the revenue in the stabilizer operation period can be considered as the outcome of this project and listed as follows, for each RBS Model.

RBS Model	Stabilizer Period	Revenue saving per day
0	None	No Interruption
1	6 – 8am & 6 – 9pm (5 hrs/ day)	Rs. 3,327 x 2 hrs + Rs. 4,227 x 2hrs + Rs. 433 x 1hrs = Rs 15,541 per day
2(a)	5 – 10am & 4 – 9pm (10 hrs/ day)	Rs. 3,327 x 3 hrs + Rs. 1,663 x 2 hrs + Rs. 4,227 x 4hrs + Rs. 433 x 1hrs = Rs 30,648 per day
2(b)	5 – 10am & 4 – 9pm (10 hrs/ day)	Rs. 3,327 x 3 hrs + Rs. 1,663 x 2 hrs + Rs. 4,227 x 4hrs + Rs. 433 x 1hrs = Rs 30,648 per day
3	Full day	Rs. 144 x 1 hrs + Rs. 289 x 3 hrs + Rs. 3,327 x 4 hrs + Rs. 1,663 x 4 hrs + Rs. 2,495 x 4 hrs + Rs. 4,227 x 4 hrs + Rs. 433 x 4hrs = Rs 49,591 per day
4	None	Rs 0

Table 7.6: Revenue saving per day calculation on each RBS Model

The expenses on the stabilizers and panel modifications can be summarized as follows. The total cost for the systems is Rs. 1,542,000 and other overheads can be assumed less than Rs. 40,000.

CASE NO	CLUSTER & RBS NAME	GEN TYPE	ATS TYPE	POWER SUPPLY	UNDER VOLTAGE RANGE	GEN RUN TIME	SOLUTION POSSIBILITY	SOLUTION FOR THE UNDER VOLTAGE			
								NEW ATS	MODIFY PANEL	3 KVA AVS FOR AC	8 KVA AVS FOR INPUT
	Kandy									1	
1	Hatharaliyadde	1 Cummins	Cummins	30A, 1ph	130-140	Continuously	YES	1		2	
2	Dambulla	2 Cummins	Cummins	30A, 1ph	175-190	4PM-10PM	YES				1
3	Wahakotte	Pending supply by CEB & already requested					NO				
4	Karagahathanna	No CEB. Gen 24 hrs Running & Transformer needed					NO				
5	Madamahanuwara	No CEB. Gen 24 hrs Running & Transformer needed					NO				
6	Galagedara	No CEB. Gen 24 hrs Running & Transformer needed					NO				
7	Katugastota	No CEB. Gen 24 hrs Running & Transformer needed					NO				
8	Ankumbura	No CEB. Gen 24 hrs Running & Transformer needed					NO				
9	Kawdupelella	No CEB. Gen 24 hrs Running & Transformer needed					NO				
10	Nildandahinna	No CEB. Gen 24 hrs Running & Transformer needed					NO				
11	Rikillagaskada	No CEB. Gen 24 hrs Running & Transformer needed					NO				
12	Dodangaslanda	No CEB. Gen 24 hrs Running & Transformer needed					NO				
	Rathnapura									1	
13	Kuruwita	3 FG Wilson	ATI63	30A, 1ph	140-160	24Hr CEB	YES	1		2	1
14	Parakaduwa	4 Temast	Hayles	30A, 1ph	160-170	6PM-11PM	YES				1
15	Neugala	5 Temast	Hayles	30A, 3ph	160-180	5PM-11PM	YES	1		2	
16	Niwithigala	No CEB. Gen 24 hrs Running & Transformer needed					NO				
17	Ingiriya	Pending supply by CEB & already requested					NO				
18	Avissawella	Pending supply by CEB & already requested					NO				
19	Endana	Pending supply by CEB & already requested.					NO				
20	Thalduwa	Pending supply by CEB & already requested.					NO				
21	Hettimulla	No CEB. Gen 24 hrs Running & Transformer needed					NO				
22	Ratnaoura	No CEB. Gen 24 hrs Running & Transformer needed					NO				
23	Kiriella	Pending supply by CEB & already requested					NO				
	Monaragala									2	
24	Mahaoya	6 FG Wilson	TI70	30A, 1ph	150-155	Continuously	YES		1	2	
25	Batticaloa	7 FG Wilson	TI70	30A, 1ph	160-165	Continuously	YES		1	2	
26	Badalkumbura	8 FG Wilson	TI70	30A, 1ph	170-175	Continuously	YES				1
27	Medagama	9 FG Wilson	TI70	30A, 3ph	170-180	Continuously	YES		1	2	
28	Wellawaya	10 Temast	Hayles	30A, 1ph	170-175	Continuously	YES				1
29	Ridipana	No CEB. Gen 24 hrs Running & Transformer needed					NO				
	Matara									1	
30	Kananke	11 FG Wilson	TI70	30A, 1ph	150-155	Continuously	YES	1		2	
31	Rilagala	12 FG Wilson	TI70	30A, 1ph	160-170	4PM-10PM	YES		1	2	
32	Gandara	13 FG Wilson	TI70	30A, 1ph	160-170	4PM-10PM	YES		1		1
33	Henaggegoda	Pending supply by CEB & already requested					NO				
34	Gatebarukanda	Pending supply by CEB & already requested					NO				
35	Mapalagama	No CEB. Gen 24 hrs Running & Transformer needed					NO				
36	Morawaka	Pending supply by CEB & already requested.					NO				
37	Kamburupitiya	Pending supply by CEB & already requested.					NO				
38	Yakkalamulla	Pending supply by CEB & already requested					NO				
	Anuradapura									1	
39	Minneriya	14 FG Wilson	TI70	30A, 1ph	165-180	Continuously	YES		1	2	
40	Galenbindunuwewa	15 FG Wilson	TI70	30A, 1ph	170-180	5PM-10PM	YES		1		1
41	Nochchiyagama	16 Hayles	Hayles	30A, 1ph	170-180	6PM-10PM	YES	1			1
42	Jayanthipura	Pending supply by CEB & already requested					NO				
	Kurunegala									1	
43	Rideegama	17 FG Wilson	TI70	30A, 1ph	160-195	Continuously	YES		1	2	1
44	Polpithigama	18 FG Wilson	ATI63	30A, 1ph	160-170	Continuously	YES	1			1
45	Maspotha	19 FG Wilson	TI70	30A, 1ph	170-180	5PM-10PM	YES		1		1
46	Karuwalagaswewa	Pending supply by CEB & already requested					NO				
	Standby Units								2	3	1
							Qty each type	**6**	**11**	**30**	**12**
							Unit cost	60,000	15,000	19,500	36,000
							Total Cost	360,000	165,000	585,000	432,000
											1,542,000

Table 7.7: Details of RBS which having highest Gen. running & possibility of the solutions

The summary of cost components are as follows.

Total cost for the voltage stabilizing systems for 19 sites = Rs. 1,582,000

Total revenue saving per month at 19 sites by extending the up time with stabilizers can be summarized for each RBS Model as follows.

RBS Model	Number of sites	Revenue saving by extended Up time	Generator running cost	Total Saving per month of all sites
0	124	Not yet considered	Few	Considerable
1	4	Rs 466,230	Rs. 89,345	Rs. 1,507,540
2(a)	6	Rs 919,440	Rs. 176,112	Rs. 4,459,968
2(b)	4	Rs 919,440	Rs. 176,112	Rs. 2,973,312
3	4	Rs 1,487,730	Rs. 419,095	Rs. 4,274,540
4	27	Not yet considered	Rs. 419,095	N/A

Table 7.8: Total saving per day calculation on each RBS Model

The total saving is around Rs. 13,215,360 per month and capital cost is only Rs. 1,582,000. Hence, without any further justification, this project is financially viable and possible to proceed.

CONCLUSION

The main objective of this project was to suggest the most economical way of running the remotely located low voltage sites by reducing the customer service interruptions while minimizing the OPEX on day to day operations. With the recorded data after one month test running period, remarkable results could be obtained and also proved that the projects is financially viable.

This development will help the company to face the challenging marketplace to sustain with the competitive Tariff reductions and demanding advancement of services to customers with minimum investment. Not like in other industry, the telecom customer is having the freedom to select any other service provider by their own decision without facing any monopoly or other influences. This automatically creates the industry to reduce their OPEX & CAPEX continually to sustain with the market share. The CAPEX is always increasing and the reduction possibility exists only with OPEX. This project could save the major portion of the OPEX by keeping other facilities in better condition and this was a remarkable achievement.

The test observations proved that the system develop for the automatic voltage regulation at remote telecom sites can operate under extreme climate, environmental & power abnormality conditions to regulate & maintain reliable & accurate sinusoidal voltage profile to the sensitive telecommunication equipments, without any single failure to the systems. In addition, the development of the unit is capable of meeting the protection requirements from various environmental/ power abnormalities and kept the sites free from any outside effects.

We believe that, the outcomes of this research will be a remarkable development in the telecom industry. We also supposed to share this knowledge with all the interesting parties to extend the benefits not only to the telecom service providers, but also to the customers by means of further reduction in tariffs.

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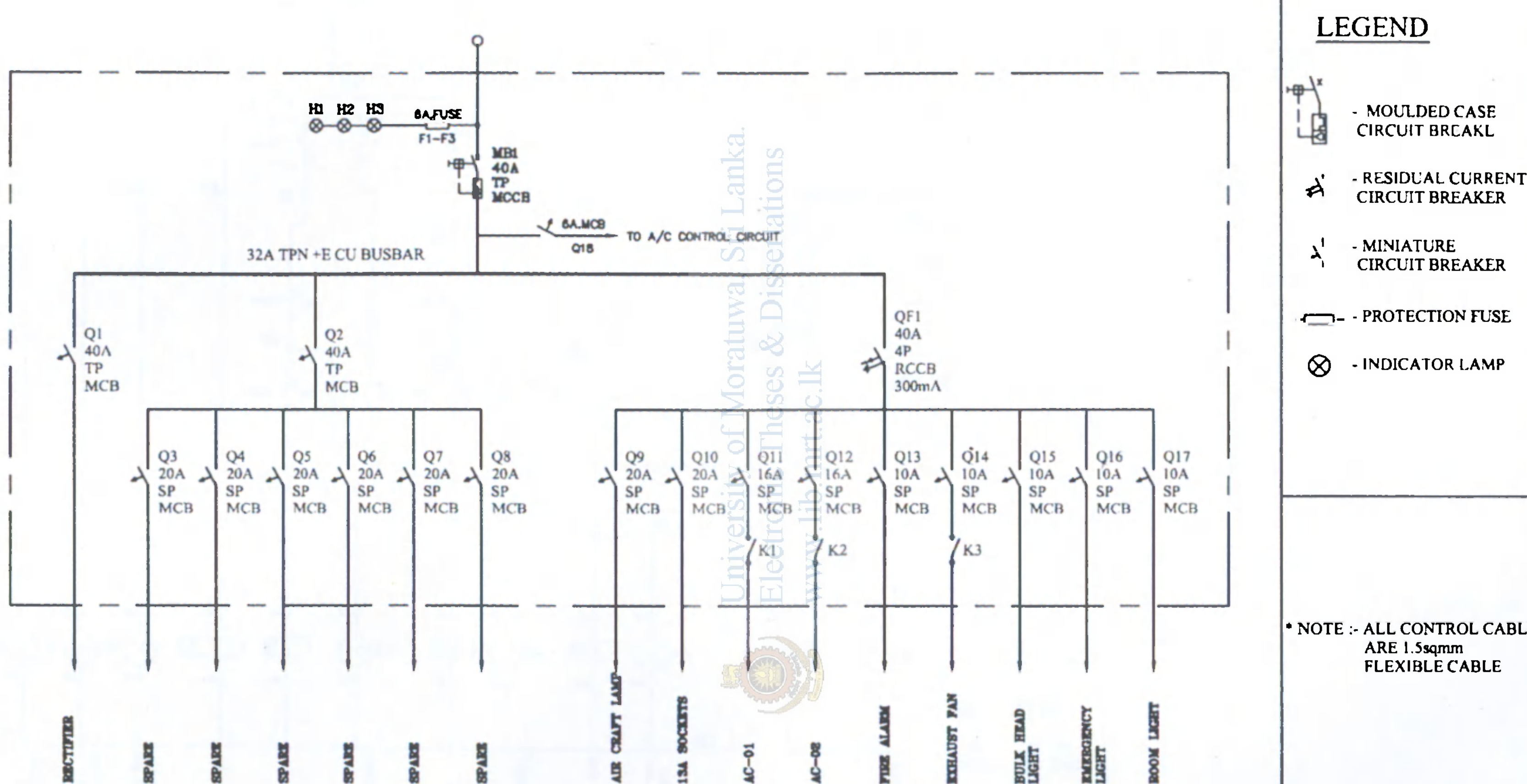
Annex-1



* NOTE :- ALL CONTROL CABLE ARE 1.5sqmm FLEXIBLE CABLE

Rev. No.	DATE	DESCRIPTION	DESIGNED BY	CHECKED BY	APPROVED BY
2					
1					
0	16.01.08	DESIGN			

CLIENT:	LANKA BELL (PVT)LTD, LEVEL 6, EAST LOWER BLOCK 1, WORLD TRADE CENTRE,ECHELON SQARE, COLOMBO 1,SRI LANKA
PROJECT:	LANKA BELL (PVT)LTD, NO:11, MAHAWELA ROAD, DEMATAGODA, COLOMBO 9,SRI LANKA.
PANEL ID:	RBS POWER PANELS
DRAWING TITLE:	SINGLE LINE LAYOUT

LANKA BELL LTD
TECHNICAL OPERATIONS DEPARTMENT

PAGE NO	02
DATE	13.05.08
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DRAWN BY	
SCALE	NTS
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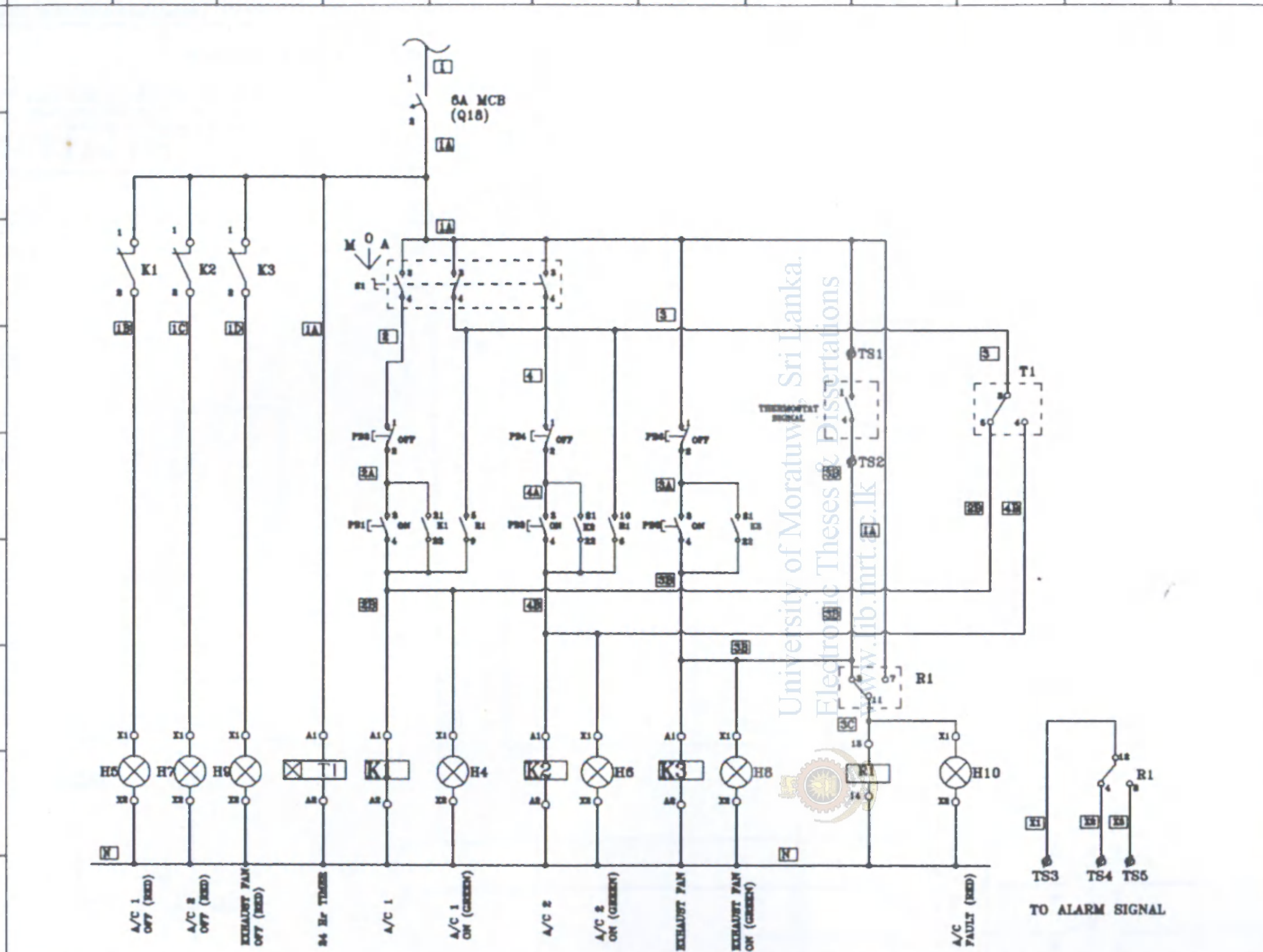
Annex-2



LEGEND

PB1-PB6 - PUSH BUTTON SWITCH

⊗ - INDICATOR LAMP

☒T1 - 24 HR TIMER

K1-K3 - POWER CONTACTOR

TS1-TS5 - TERMINAL STATION

S1 - AUTO / MANUAL SELECTOR SWITCH

* NOTE :- ALL CONTROL CABLE ARE 1.5sqmm FLEXIBLE CABLE

Rev No.	DATE	DESCRIPTION	DESIGNED BY	CHECKED BY	APPROVED BY
2					
1					
0	16.01.06	DESIGN			

CLIENT: LANKA BELL (PVT)LTD, LEVEL 6, EAST LOWER BLOCK 1, WORLD TRADE CENTRE,ECHELON SQARE, COLOMBO 1,SRI LANKA.

PROJECT: LANKA BELL (PVT)LTD, NO 11, MAHAWELA ROAD, DEMATAGODA, COLOMBO 9,SRI LANKA.

PANEL ID: R.B.S. POWER PANELS

DRAWING TITLE: CONTROL DIAGRAM

LANKA BELL LTD
TECHNICAL OPERATIONS DEPARTMENT

PAGE NO	03
DATE	13.05.08
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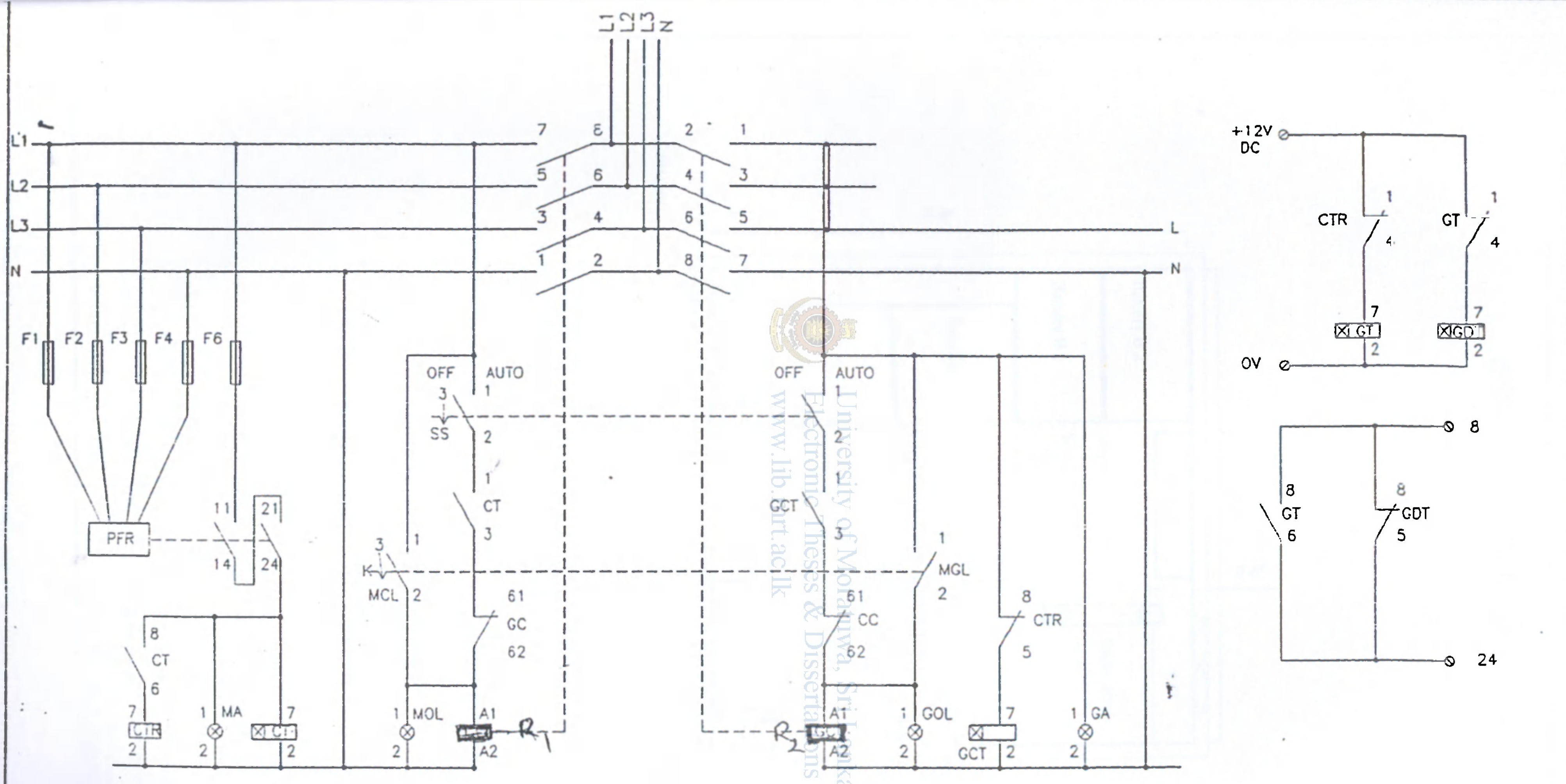
DRAWN BY	
SCALE	NTS
CAD FILE	GAY/COM/07/REL/LANKA BELL

Annex 3



GT – GENERATOR STARTING TIMER(6S)
GDT – GENERATOR COOLDOWN TIMER(3M)

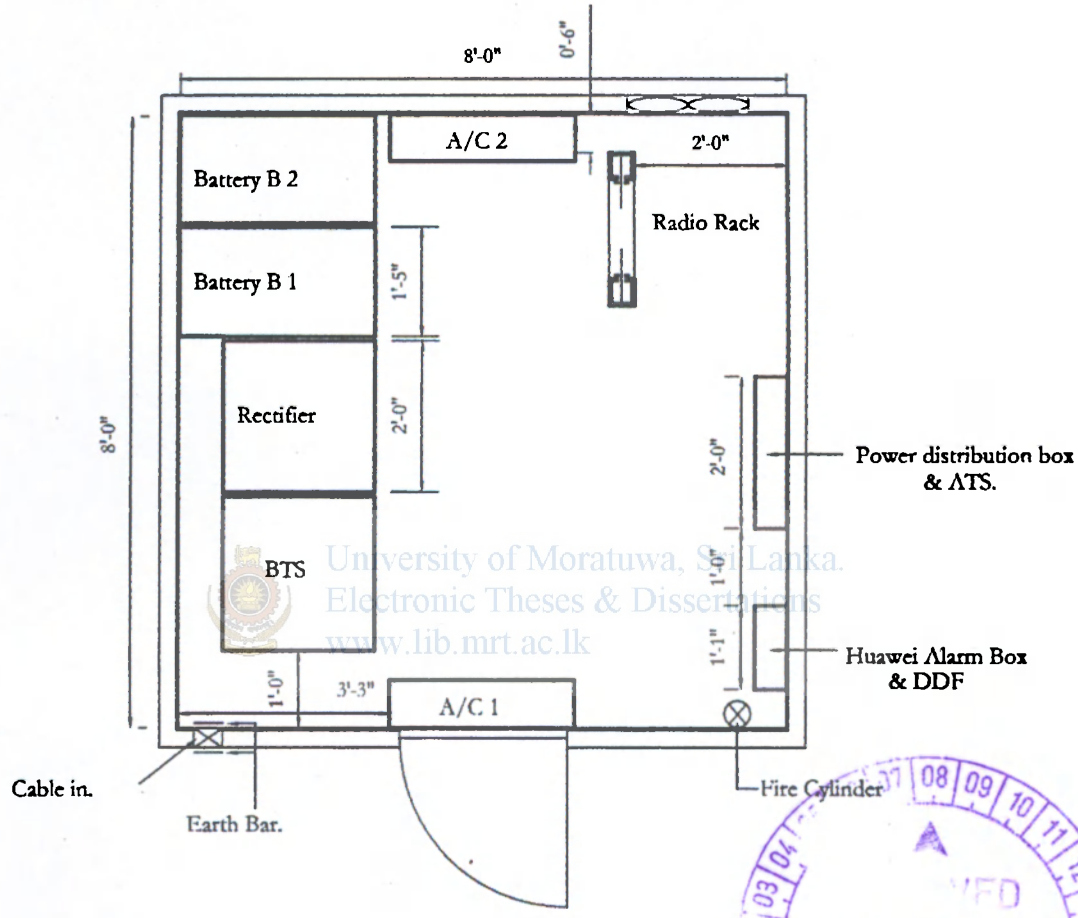
PFR – PHASE FAILURE RELAY
CT – COMMERCIAL POWER SENSING TIMER (10S)
CTR – COMMERCIAL POWER SENSING RELAY
CC – COMMERCIAL POWER CONTACTOR
GC – GENERATOR POWER CONTACTOR
GCT – GENERATOR POWER SENSING TIMER (10S)

SS – SELECTOR SWITCH FOR AUTO/OFF
MCL – MANUAL COMMERCIAL POWER LOAD KEY SWITCH
MGL – MANUAL GENERATOR POWER LOAD KEY SWITCH
MA – MAINS AVAILABLE BULB
MOL – MAINS ON LOAD BULB
GA – GENERATOR POWER AVAILABLE BULB
GOL – GENERATOR ON LOAD BULB

LANKA BELL PVT LTD.
ENGINEERING & CONSTRUCTION DIVISION

DWG. TITLE: AUTO MAINS FAILURE	
DESIGNED BY: ARUNA AMARASENAKA	DRAWN: Dayananda DATE: 28/05/02
CHECKED BY:	SCALE: N.T.S. REV.
APPROVED BY:	CAD FILE:

ANNEXURE 04 - (CABIN DRAWING)



PROPOSED SHELTER PLAN

Scale - N.T.S

SHEET No.

LANKA BELL PVT LTD.

LANKA BELL

PROJECT & PLANNING DIVISION
No.344, GALLE ROAD, COLOMBO - 03
TEL 94-115-339933, 322215 FAX 94-115-514349

DWG. TITLE
PROPOSED SHELTER PLAN AT PERIYA KINNIYA.

DESIGNED BY: | DRAWN: Shalitha | DATE: 02/12/2008

CHECKED BY: | SCALE: AS SHOWN | REV.

APPROVED BY: | CAD FILE:

DWG. No: CDMA-SHELTER-PERIYA KINNIYA-0001