IMPACTS OF MOTOR STARTING IN AN ALUMINIUM PROCESSING PLANT

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Abstract

This paper embarks on an investigations leading to the understanding of the problems of the dependence of Aluminum Processing Plants (APP) on electric motors making use of computer analysis. A numerical example is performed utilizing data got from typical factory operations and results/outcomes presented..

Introduction

The dependence of the Aluminum Processing Plant (APP) on electric motors of different ratings has been assessed. Random starting of these motors mostly Direct-on-Line (DOL) produces transient voltage effects like depressions (fig. 2); these in turn add quite adversely to the high current problems that follow the constant "Dead Short" operating conditions of the APP. The starting of the larger motors DOL can substantially limit the motor output torque and at the same time increase stalling possibilities in all electrically nearby motors as well as influence the operational levels of any local loads served by the motor buses. Mastering these conditions is essential to the assessment of motor starting effects on an APP.

Generally, the aluminum and iron industry remains the highest single user of electrical energy and according to utility sources, it is estimated that about 300kwh are used up per ton of ingot and about 200kwh in one rolling operation. Investigations leading to more understanding of the problems have also been carried out with the help of a computer analysis. Several other types of studies related to special starting characteristics of typical motors have been suggested and described. Finally, results and outcomes of computer aided tests have been made available.

Characteristics of this APP

This study is particularly interesting for the following reasons, first is the need to throw more light on particular problems that beset the test-case industry prior to its shut down and subsequent rehabilitation. Second is the importance placed on aluminum development associated metallurgical concerns by the Federal Government of Nigeria as well as by most other developing countries. This APP is located at Emene Industrial Estate of Enugu in Enugu State South-East of Nigeria. We equally have such types at Onitsha in Anambra State and at Uyo in Akwa-Ibom State.

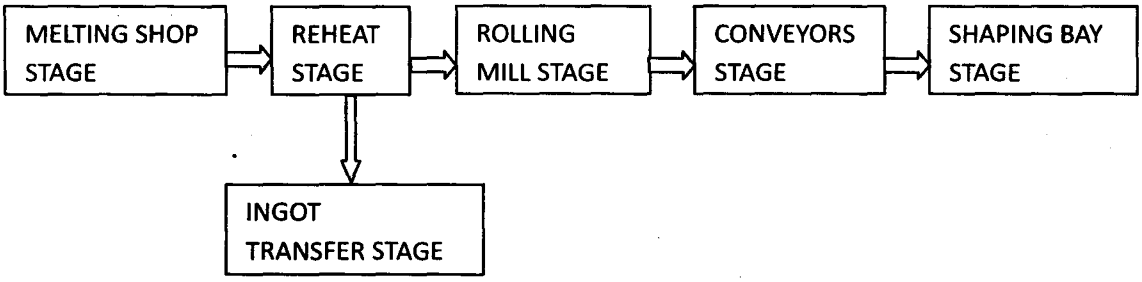

Fig. 1: Block Diagram of Operational Stages of APP.

Problems of Voltage Depression

The most notable impacts of motor starting in this APP as well as in most other similar industries is the voltage depression that is experienced during DOL starting (1). In the operation of the APP, the voltage level to be maintained at the melting shop should be at least 80 percent of rated (2). This voltage level requirement resulted from critical examinations of the torque-speed characteristics of the various rating of motors employed in the melting shop stage. These produce at 1.5p.u. starting torque at full terminal voltage. Consequently, at a depressed starting voltage of 0.8 p.u., the breakaway torque, which varies as the square of voltage, becomes:

$$T_{ST} = (0.8^2 \text{ x } 1.5)\, T_{rated} = 0.96T_{rated} = 10T_{rated} \quad \ldots\ldots\ldots\ldots (1)$$

The functions of the 25kw, 400v Hoist DC shunt motor involve driving the crane hooks that lift up to 50 tons of scraps to i.e. the furnace and casting the molten aluminum into the ingot moulds. Along with the auxiliary 2.4kw 5.3kw crane crab and long travel special type induction motors respectively, the need for high starting torque can be appreciated. The 15kw hydraulic motor which drives the hydraulic system that lifts the furnace root for tilting during casting operations is particularly useful with a high starting torque.

Different other problems often arise due to the voltage dips that characterize motor starting. Motor drives in running conditions slow down as result of starting effects one single large motor or of a combined impact from simultaneously starting several small motors. It is often require that the running motor(s) should be able to reaccelerate as soon as the starting motor(s) attained full-load speed. However, serious starting depressions may still result from a cascading effect caused by the decelerations from individual motors reacting to steadily increasing loading. If this condition is left uncontrolled, the possibility of the loss of all loads becomes increased.

Stiffness of Supply

The aluminum plant is powered by a 33kw supply directly from Power Holding Company of Nigeria (PHCN) substation at New Heaven Enugu. Putting into consideration the low industrial density of the location, this linkage arrangement would normally be regarded as "stiff".

However, due to the remoteness of the generation and the presence of an on-site generation capacity which comes on exclusive of PHCN supply, the power supply arrangement can be grouped as weak (3). It is common for standby generators to worsen the voltage dip problem due to their relatively high transient impedances during motor starting (4).

Situations like this very often leave the aluminum plant operators with losses resulting from "crusting", an effect that follows insufficient temperatures. However, the electrodes may be wasted due to low arc temperature since its direction of rotation; lifting and its lowering for scrap contact or disengagement depend on this.

The problem of weak source generation has been combated by the Emene APP through the use of a 1.8MVA synchronous compensator. This has been hooked to the factory bus through a 33KV/6.6KV 5.0MVA step-down transformer. During factory operations, it is run steadily to provide power factor improvement for the entire electrical system. This is possible since it normally runs at leading power factor. Other function of it includes: ventilation, pumping and compressor duties.

Torque Requirements for the Rolling Stages

Under carefully controlled conditions, different sizes and ratings of motors are operated daily to meet the torque requirements traverse the reheat, Rolling Mill and Rolling Bay stages of the APP. These include the 11kw Ingot pusher and Roller motors that respectively drive the hydraulic systems which push input along the length of reheating furnace and deliver same to the Cogging mill. The 0.4MW, 525V cogging mill induction motor is of particular interest since it is fitted with an on-load starter which can act automatically but retains the capacity of adding resistance to the rotor circuit externally in order to have maximum starting torque of about 2.8×10^3Nm, this device can also cut off the rotor resistance trapping a circuit breaker when the rotor speed exceeds the specified range. There is equally the 18.5kw side cutter motor which helps to trim/cut bars during reduction process. At the finishing mill is a 485KW, 525V motor which drives the last set of mills to reduce the elongated bars to their final dimensions as reinforcement bars.

Parts of the control needed for these and other motors would be to start on-load through gearing connections. This arrangement provides for some form of "slackening" in the gears and complying during acceleration within low-torque periods i.e. run-up time.

In all, there is a composite torque requirement of $30 \times 10_3$Nm rated for all the motors in an average commitment time of 6 hours. The air-gap (electromagnetic) torque produced by an induction motor (wound rotor or squire cage) be described approximately as follows:

$$T_s=K_1SE_1^2R_2/R_2^2+(Sx2)^2 \ldots\ldots\ldots\ldots(2)$$

where the subscripts 1 and 2 show stator and rotor quantities respectively. The response of the cogging mill motor to variations in its rotor resistance is demonstrated by the Torque/Slip curves shown in figure 3 as well as by the torque equation.

Problem Alleviation

Clearly identifying and showing the extent of the voltage depression are closely linked to a thorough motor starting study. Such a study should be facilitated by the availability of a variety of motor voltage profiles and other ratings. Therefore, reduction of this problem will be based on the realization that the huge starting current drawn by the induction motor is directly proportional to the stator voltage. Corrective measures such as off-nominal tap for two 1.8MWA auto-transformer starters are some of the most effective means of realizing reduced and adequate starting voltage. This method has been carried out mainly for the large squirrel cage induction motors.

Normally, the performance assessment of these motors requires to be carried out only with an exact specification of the bus voltage at any given time. However, the two approaches that are adopted towards achieving the bus voltage conditions and in their ascending order of complexity are:

a) Impedance Method

A simplified impedance circuit as shown in fig.4 was considered. Then,

$$\mathbf{V_t=V_s(X_s/X_s+X_m) or V_t=V_s(Z_s/Z_s+Z_m)\ldots(3)}$$

where the subscripts t, s, and m represent motor terminal condition , system component and motor component respectively. Regulation of the motor bus voltage, V can be realized through the addition of negative Vars from the synchronous reactor. This will make system impedance, Z_s to become larger and therefore increase the voltage, V_t towards a 1.0 p.u. limiting value. It is therefore advisable to use complex qualities during impedance method calculation in order to obtain results within reasonable accuracy.

b) Bus Current Method

The fundamental equations used to describing the bus conditions were obtained as follows [s].

$$\mathbf{1p.u.}=MVA_{load}/MVA_{base}\ \mathbf{for\ a\ 1.0p.u\ .voltage\ldots\ldots\ldots\ldots(4)}$$

Furthermore, the voltage drop and motor bus voltage were calculated as follows:

$$\mathbf{V_{drop}=1p.u.xZp.u and V_t=V\text{-}_sV_{drop}\ldots\ldots(5)}$$

where: $Z\ p.u$ is identical X_s (p. u.) considering lossless conditions.

It can be shown that the disadvantage associated with this method is the non-uniformity of current individual load relationships as a result of variations of voltage levels. Iterative procedures for obtaining solutions are normally needed for the differential equations that result in such cases. Thus:

$$\mathbf{1_k=(P_K\text{-}jQ_k/V_k)-Y_kV_k}$$

$$\mathbf{V_k=V_s+\sum_i{}^n{}_{+1}Z_{ki}}$$
$$\mathbf{=V_s+\sum_i{}^n+_1Z_{ki}[(P_k-jQ_k)\ldots\ldots\ldots\ldots\ldots(6)}$$

where

$\mathbf{1_K}$=Current in K^{th} branch of APP network

$\mathbf{P_kQ_k}$= Real and Reactive Powers at K^{th} bus

V_k =Voltage at K^{th} bus

Y_k=Shunt admittance to ground of bus K

V_s=Voltage at factory bus (swing or slack)

n=Number of buses in factory network

Z_{ki}=Impedance between K_{th} and i^{th} buses.

The form of solution needed for equation (6) is the Gauss Iterative method using Z bus. It is also most suitable for a complete analysis but due to the volume of mathematical application needed, should the factory network be multi-bused, then hand calculations may become very tedious, hence leading to computer aided approach

Experimental Investigation

Making use of available data, the performance and impact of the 485KW, 525V finishing mill motor were evaluated. In addition to these is the fact that this motor often starts on load at 90 percent plus of rated voltage instead of the 85 percent theoretically envisaged. Making use of the motor locked rotor current of 593.3amperes, and for a full-load rotor current of approximately 5 times less, the investigation went thus:

$V_{drop}=V_s-V_t+IR+IX$..........(7a)

or from fig. 5,

$V_{drop}=V_s-V_t + (IR\cos\theta)^2 + (IR\ \sin\theta)^2 + (1x\cos\theta)^2+(1X\sin\theta)^2$.........(7b)

Where

I = motor current in amperes

R = Motor feeder resistance

X = Motor feeder reactance

V_s = 317.92V/phase of factory bus

V_t = Motor terminal bus voltage per phase

Therefore

$$V_{drop/phase} = V_s + IR + IX - V_t$$

$$V_{drop/phase} = 39.852V/phase.$$

Consequently, the actual 3-phase motor terminal voltage, V_t determined as a percent rating becomes:

$$\%V_t = \frac{(Vs - 3Vdrop)\ (100)}{V_t}$$

$$= \frac{550-25.39x1.73x100}{525}$$

$$=96.40\%$$

Discussion

The findings shown above reveal that the prediction of the current level at motor bus is within reasonable accuracy. Control of the starting voltage will minimize the motor inrush current and thus reduce the total line drop. However, a careful selection of low impedance line conductors would also help greatly, as was demonstrated above, in the minimization of line drops.

Conclusion

The usefulness of the auto-transformer for reduced starting voltage and of the rotor resistance selector for enhanced starting torques have respectively shown encouraging results dur serve as a guide for future finding of the impacts of motor starting on an APP and also prove essential in collecting needed information for more detailed type of study.

Acknowledgement

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Recommendation

The authors wish to recommend that installation of adequate control of starting voltage, that will reduce the motor inrush current and further minimize the total line drop be put in place. Also that a careful selection of low impedance line conductors would also help greatly in the minimization of line drops.

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APPENDIX

The role of computer-aided analysis can never be overemphasized due to an ever-increasing need for bigger and better operated engineering systems. This need can only be met by the availability of accurate system specifications provided only by the electronic computer. In view of this, the power-flow analysis of the mill motor feeder network has been carried out with the aid of the computer. Shown below, therefore, is a reproduced computer output showing the voltage dip on the motor starting.

This has been detailed from the revised impedance diagram showing the transient reactance of the system. See figure A2.

NO	BUS NAME	BRANCH FROM	BRANCH TO	VOLTAGE (P.U.)	ANGLE (DEGREES)
1.	Factory Pri.	1 1	5 2	0.925	-4.360
2.	Factory Sec.	2 2 2	1 3 4	0.879	-6.835
3.	0.5MWA XFMR. SEC.	3	2	0.866	-9.365
4	Motor Bus	4	2	0.835	-9.290
5. Line	Swing Buses	5	1	1.048	0.000
4	5				

Fig. A1: Reproduced Load Flow Computer Programme Output.

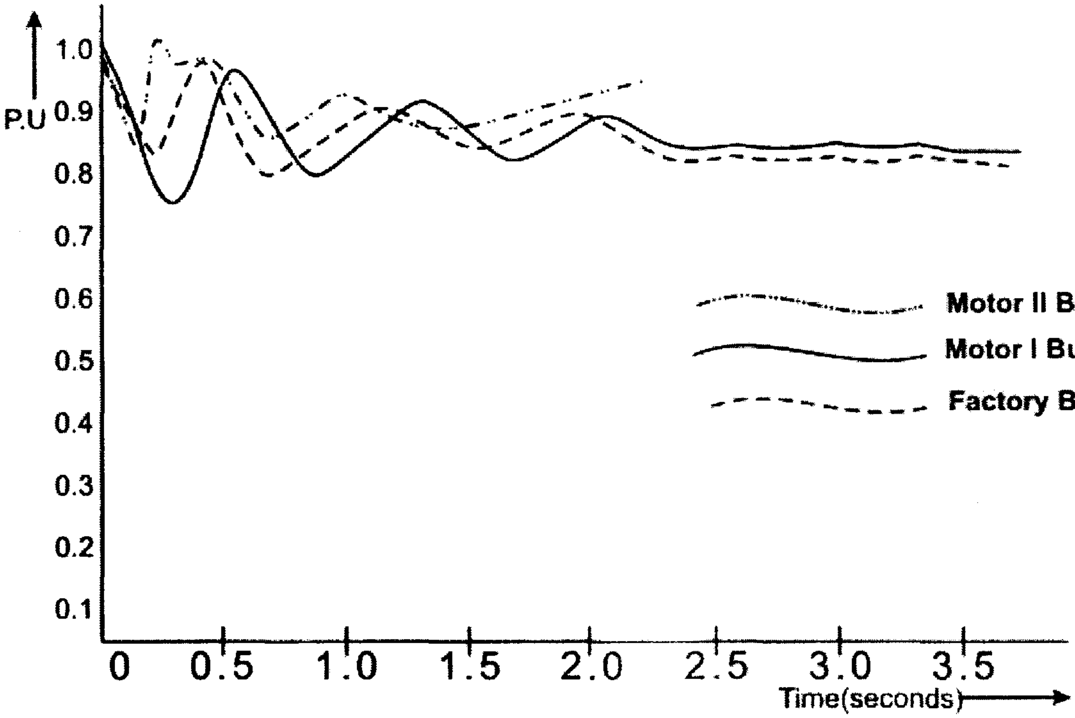

Fig. 2: Typical Factory Bus Voltage Characteristics for Motor Starting

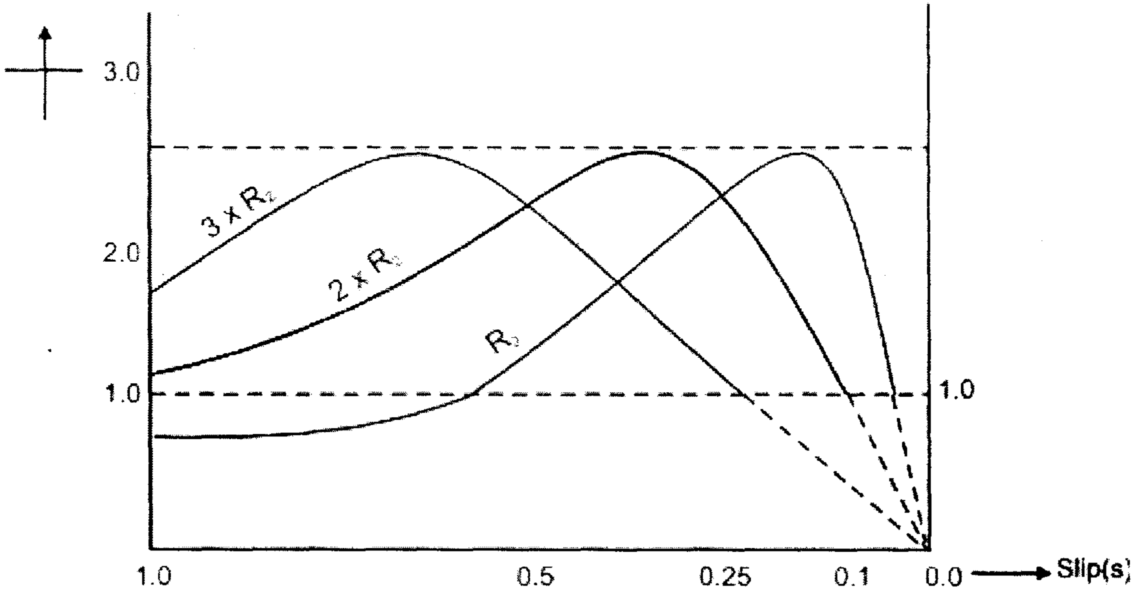

Fig. 3: Typical Torque/Slip Characteristics for Various Rotor Resistance

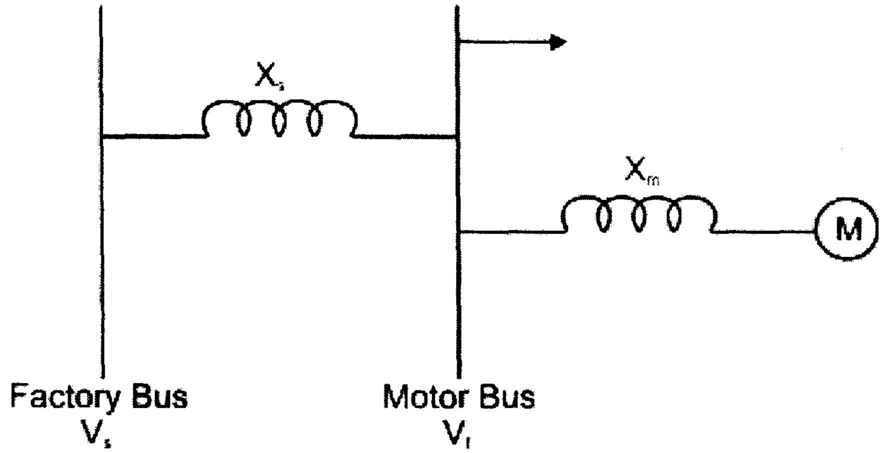

Fig. 4: Simplified Imperial Speed Diagram

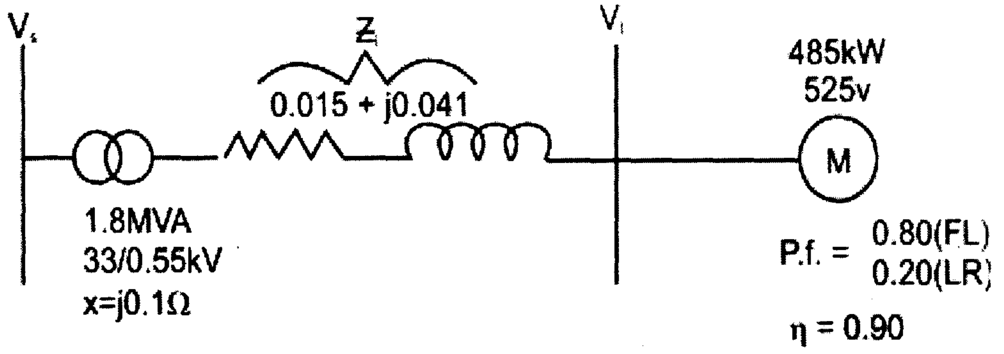

Fig. 5(a): One-Line Diagram of Factory Motor Feeder

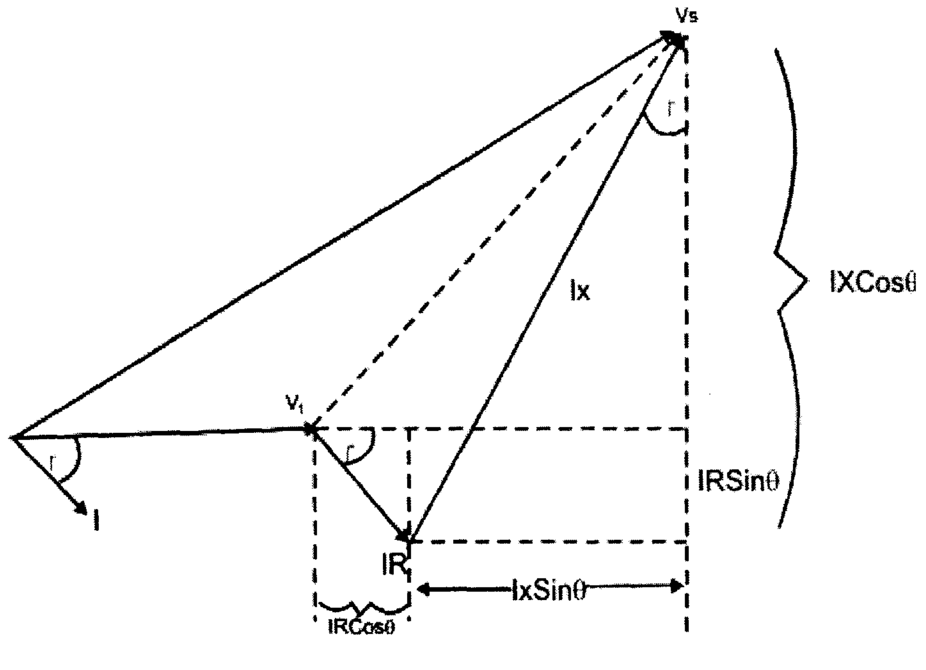

Fig. 5(b) Vector Diagram of Motor Feeder Circuit

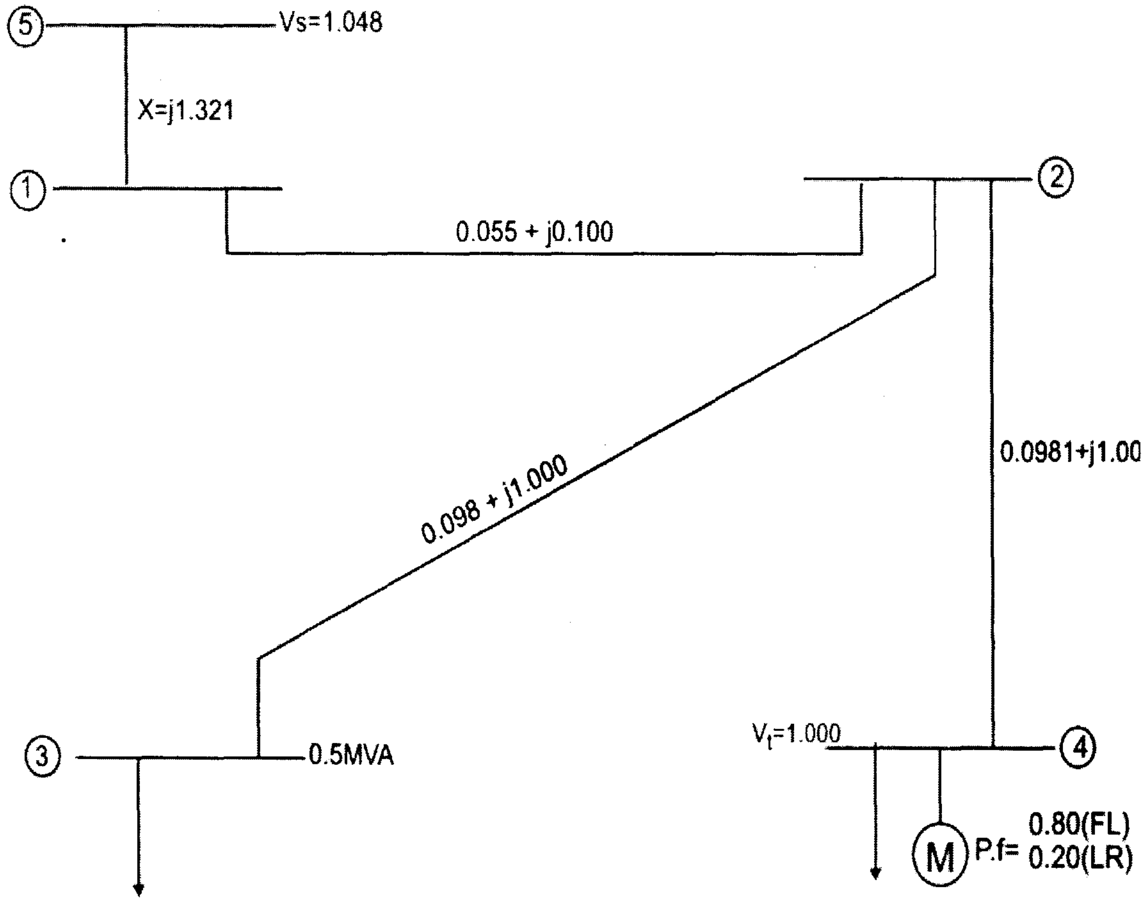

Fig. A2: 5. BUS Load -Flow Power System impedance Diagram