# ELECTRICAL SUPPLY IN WARSHIPS

## A BRIEF HISTORY

BY

LIEUTENANT-COMMANDER JOHN M. MABER, R.N. (RET)

## PART I

### Early Generators and Uses of Electricity

The invention of the electric generator stemmed from a series of experiments carried out by Michael Faraday (1791–1867) between August and December 1831[1] but, other than small machines employed for electro-plating and similar light work, it was not until the eighteen fifties that Frederick Holmes working in England developed a successful permanent-magnet excited continuous-current dynamo capable of a useful sustained output of any magnitude. In the meantime, the electric arc lamp had been developed and, towards the end of that decade, this was adapted to meet the needs of the lighthouse, the first installation in the United Kingdom being that demonstrated at South Foreland on the 8th December 1858. For this Holmes, with the backing of Faraday, supplied a pair of dynamos, belt driven at 90 rev/min by 2¾ horse-power non-condensing steam engines. This combination represented the first stage in the practical development of an electrical supply industry which was soon to transform the face of the industrial world and to have a profound influence on the design of ships both for war and for commerce.

The next stage in the development of the electric generator was in 1856 when the German engineer Werner Siemens took out a British patent for a permanent-magnet-excited machine with a shuttle-wound armature rotating between magnet pole pieces shaped to give a minimal air gap. A simple two-segment commutator served to rectify the armature output.

Ten years later, Henry Wilde described the principle of the separately-excited alternating-current generator or alternator, the excitation current for which was derived from a small belt-driven permanent-magnet-excited magneto-generator. In February 1867, William Siemens[2] (probably inspired to a large extent by his brother Werner) and Sir William Wheatstone working quite independently presented papers to the Royal Society specifying the requirements for self-excited continuous-current generators which relied on the residual magnetism of the magnet core to initiate excitation. The main difference was that Siemens's machine had field coils wound in series with the armature and in Wheatstone's machine they were shunted across the brushes.

In that same year, Wilde modified a number of separately-excited direct-current machines for self-excitation by connecting the field winding as a shunt across the armature, and this, coupled with simultaneous work by Farmer in the United States, resulted in the development of the shunt-wound dynamo. Within a few months, series-wound and shunt-wound direct-current machines became accepted on both sides of the Atlantic for small-scale commercial work. Series-wound machines of the Siemens type with a rising voltage characteristic were, however, suited only for working into a relatively constant load, e.g. a carbon arc-lamp. It was the shunt-wound, and later the compound-wound, machine which was to be exploited for commercial and marine direct-current development.

Early arc-lamps suffered from the poor quality output from permanent-magnet-excited dynamos, but the advent of machines such as those of Wilde and of Siemens brought about some improvement. More germane to the problem at this stage, however, was that in-service experience together with work by Serrin, Linton, Brush, Crompton, and others resulted in considerable improvement in the design of the lamps themselves. Various forms of carbon feed, hand and automatic, were developed and the arc-lamps of the eighteen seventies required little attention in service other than cleaning and the fitting of new carbons when necessary.

Although William Siemens contributed little to the development of the commercial arc-lamp, manufacturing rights were acquired enabling Siemens Bros. to market complete installations. In December 1871, trials were carried out at Sheerness[3] with a '. . . dynamo-magneto electric light in the torpedo service . . .'; quite what this involved is not clear but certainly at this stage little thought appears to have been given to the possible uses of electric lighting at sea.

Lighting apart, practical use was first found for electricity in H.M. ships in the early eighteen seventies with the introduction of the electric gun-firing circuit energized by a Pile battery comprising 160 elements of copper and zinc plates separated by fearnought soaked in a mixture of vinegar, salt, and water. This relatively high voltage and therefore somewhat unsatisfactory series-connected power source was replaced in later installations by a series-parallel arrangement (9 volts) of Leclanché cells. At about the same time, electric cabin call-bells were introduced in some North Atlantic liners.

A major advance in the quality of direct-current supply stemmed from the work of the Belgian engineer Z. T. Gramme who, in 1870, developed the ring-wound armature with the junctions between adjacent coils brought to a multi-bar commutator. His original machine had two poles, but later much larger multi-polar versions were built by the Gramme Company. The Royal Navy used machines of this type, the first being an 80-volt dynamo fitted in the battleship *Inflexible* in 1881 to supply the searchlights.

The limitations of the ring-wound armature were that the coils had necessarily to be wound laboriously *in situ* by hand and, furthermore, more than half the copper was positioned clear of the magnetic field where it did little other than contribute to the heat losses. In 1873, the German engineer F. von Hefner Alteneck, combining the principles of Siemen's 'shuttle' armature and Gramme's 'ring' winding, developed the 'drum' winding wherein the coils were distributed symetrically around the surface of a cylindrical core of either iron or wood bound with iron wire. Although this method permitted the use of pre-formed coils, for large machines the problem of centrifugal forces had to be overcome by placing the coils in longitudinal slots around the armature core where they were secured in position by hardwood wedges.

In 1879, Thomas Edison in the United States built his first lighting dynamo, a two-pole machine with a drum-wound armature, intended to supply a series circuit comprising an arc-lamp and a number of incandescent lamps. Subsequently, Edison dynamos were widely used in America and Europe, and in 1883 a machine of this type was installed in the U.S. cruiser *Trenton*. In England, the manufacturing rights of the Edison dynamo were acquired by Messrs. Mather & Platt of Manchester and, in 1882, a London consulting engineer, John Hopkinson, made a critical examination of the Edison dynamo aimed at increasing its output and efficiency. This resulted in 1886 in the manufacture by Mather & Platt of the prototype Edison-Hopkinson dynamo developing more than double the power of a basic Edison machine of similar size.

By 1880 on both sides of the Atlantic, reasonably reliable generating plant could be supplied to meet the needs of any lighting system. The choice between d.c. and a.c., however, seems to have been a matter of personal whim on the part of the designer. In fact, the first generator employed at sea was a primitive Wilde alternator, although on balance the direct-current system was probably the more widely preferred.

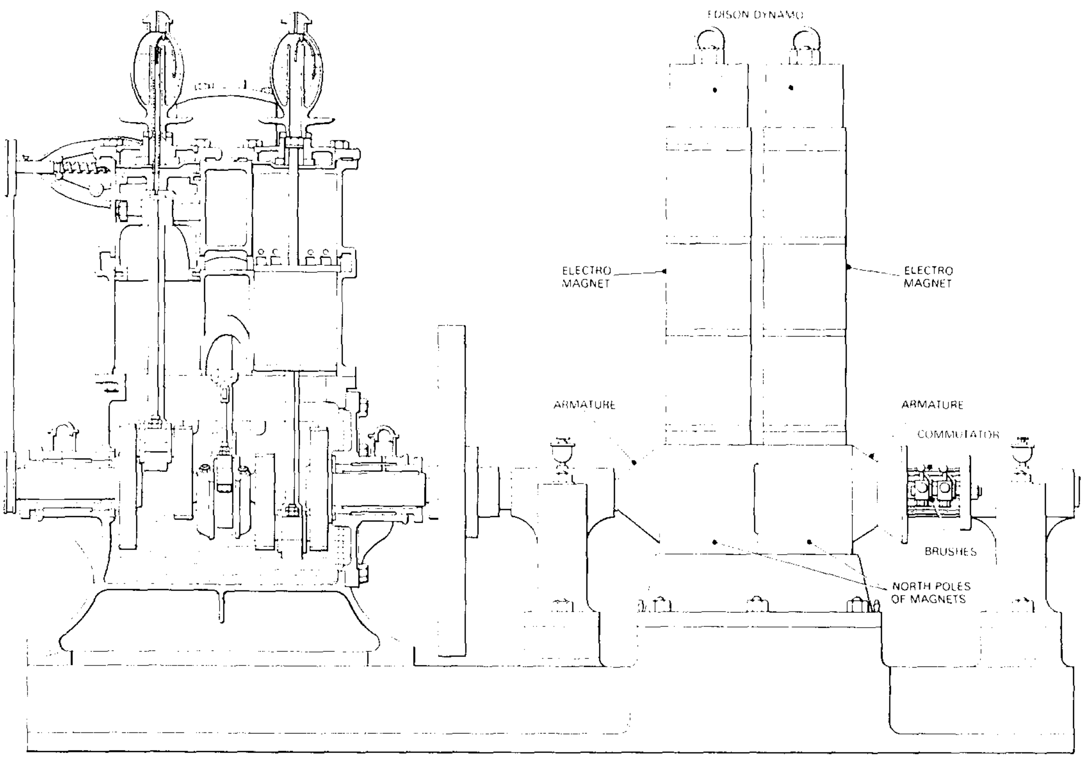


FIG. 1—TYPICAL EDISON DYNAMO SET c1885 WITH WESTINGHOUSE COMPOUND ENGINE DRIVE

At this period, the installed capacity for lighting purposes was miniscule—ten or twenty kilowatts in a passenger ship and up to fifty kilowatts in a battleship where the searchlights represented a considerable part of the total load. By the eighteen nineties, however, with the introduction of electric ventilation and other motor-driven auxiliaries, the rapid upswing in power demand brought about the need to give serious consideration to the design of the supply and distribution system itself.

A direct-current supply was better suited for motor-driven equipment: shunt- or compound-wound machines were adapted for variable-speed drive, simple series-wound motors with high starting torque were suitable for ventilation fans, and a combination of the two (predominantly series connected for hoisting and predominantly shunt connected with regenerative breaking for lowering) met the requirements of deck machinery. Thus, by the turn of the century, the direct-current system had been recognized almost universally for marine installations and, in general, this line of development was pursued for the next fifty years.

## Searchlights and Lighting

A Torpedo Committee was set up by the Admiralty in 1873 to consider defensive measures against the torpedo-boat (the forerunner of which was developed by the Confederate Navy in the Amercian Civil War). Amongst other requirements was the need to be able to detect a darkened craft at night.

At this time, Henry Wilde drew the attention of the Admiralty to the possible use of the electric searchlight which in its primitive form comprised a hand-fed arc lamp positioned in a cylindrical barrel at the approximate focus of a dioptric lens system. Successful trials were carried out in the twin-screw gunboat *Comet*[4] which was fitted for the purpose with a Wilde alternator driven by a 6 hp steam engine. The 22-inch diameter searchlight developed 11 000 candle-power producing a beam capable of illuminating a pale-coloured target at a

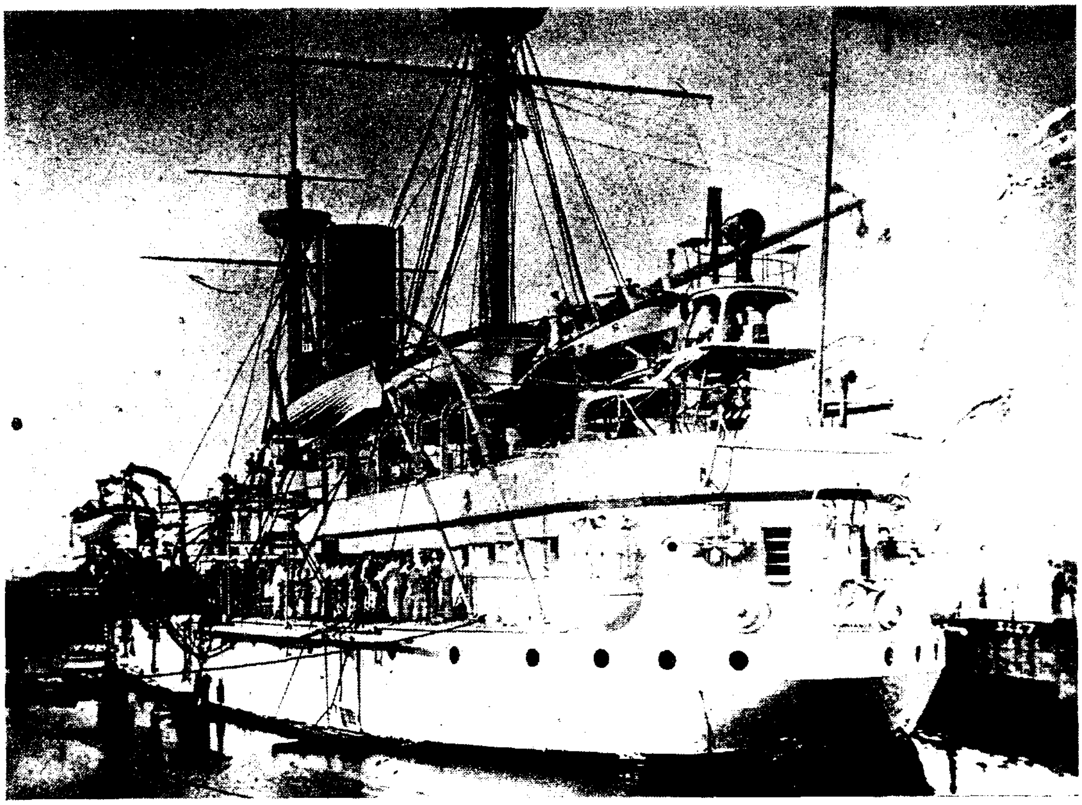

FIG. 2—H.M.S. 'AGAMEMNON' 1883 (SHOWING SEARCHLIGHT INSTALLATION)

distance of a mile and a black-painted craft at about half a mile, still well outside the 400 yards or so effective range of the contemporary Whitehead automobile torpedo. Although the beam was too narrow to illuminate the whole target, no other form of illumination was capable of meeting such a requirement and the immediate future of Wilde's 'electric light' was thus assured.

In 1876, a searchlight was installed in the 6621-ton ironclad battleship *Minotaur*, and shortly afterwards the battleship *Temeraire* was similarly equipped. Power for the arc-lamp as supplied by a 32-magnet self-excited Wilde alternator belt driven at 400 rev/min from an auxiliary pump engine, the excitation current for the field being derived from the rotor circuit via a commutator. This improved-design 22-inch Wilde projector was fitted with a hemispherical reflector and dioptric and divergent (in the horizontal plane only) lenses, although the carbons were still fed by hand. Amongst other vessels similarly fitted in 1877 were the battleships *Dreadnought* and *Neptune*.

As all-round coverage could not be achieved (with particular reference to fully-rigged ships of the 'up-funnel, down-screw' type) by means of a single searchlight, later installations comprised two or more lamps; the first vessel so fitted was the barque-rigged central-battery ironclad *Alexandra*, completed in 1877, which was equipped with two 24-inch searchlights, one each side amidships.

An improved installation designed by Siemens Brothers was fitted in the wooden-hulled ironclad *Repulse* in 1880. This comprised four d.c. generators (dynamos) arranged in pairs (each pair being driven by a single Brotherhood three-cylinder radial simple-expansion steam engine) connected in parallel to supply a 24 inch 18 000 candle-power lamp. A switchboard was provided enabling either pair of dynamos to supply each of the three searchlights. A similar installation but with only two lamps was fitted in the central-battery ironclad *Triumph*. The *Sultan* and *Inflexible*, however, were fitted with 20 000 candle-power lamps of Gramme's design which proved in service to be more robust than the Siemens lamps and were adopted for the battleships *Ajax* and *Agamemnon* then under construction.

Similar development was taking place at the same time in the French, Russian, and United States navies: the French ironclad battleship *Richileu*[5] was fitted with a direct coupled dynamo to power a searchlight installation and the U.S. torpedo-boat *Lightning*, a 58-foot wooden-hulled craft, was fitted with a Farmer's carbon-arc searchlight operated by the helmsman.

Searchlight installations were, of course, a specialist warship requirement and little interest was shown on the part of commercial operators in electric arc lighting. Although such lighting was fitted in a very limited number of ships about this time, the widespread introduction of general purpose electric lighting had to await the development of the incandescent lamp, the first practical version of which was patented by Thomas Edison in the United States in 1878. These early carbon-filament lamps proved fragile and short lived. However, it was his development of the carbonized cellulose filament in 1879 together with the development by Joseph Swan in England of an improved method of evacuating the lamp bulb with the filament at incandescence which led by 1883 (when Edison and Swan jointly formed the Edison & Swan United Electric Light Co. Ltd.) to incandescent lighting systems being specified for many new construction passenger steamships and warships.

**Early Distribution Systems**

At the time that electric lighting was installed in the new battleship *Inflexible*, there was little experience on which to base system design. An 800-volt d.c. supply was adopted feeding a complicated series-parallel system of arc-lamps in the engine and boiler rooms and Swan 'glow' incandescent lamps elsewhere. The 'glow' lamps were connected in circuits of 18 lamps in series between the main supply bus-bar and the arc-lamps. Each glow-lamp was fitted with an automatic cut-out bringing into circuit a substitute resistance of similar ohmic value in the event of lamp failure. There were no local switches.

Commissioned in 1881, H.M.S. *Inflexible*'s system proved reasonably successful, but a combination of the high voltage and an earth fault unfortunately resulted in the first fatal accident due to electric shock in one of H.M. ships. As a result, 80-volt d.c. complete-wire circuit was adopted as standard Royal Navy practice. It was also decided at this time that a common electrical system should be used for internal lighting and searchlights, *Inflexible* having had separate sources of supply for each.

In 1881, an Instructional Electric Light Shop was approved for H.M.S. *Ariadne* then forming part of the Vernon establishment at Portsmouth, and three years later H.M.S. *Defiance* was commissioned at Devonport with facilities for theoretical and practical electrical training.

The 2640-ton armoured torpedo ram *Polyphemus* which was built at Chatham before the decision was taken to adopt complete-wire systems had an 80-volt d.c. earth-return system supplying incandescent lighting and an electric lamp on her single-pole mast for '. . . signalling and reconnoitring purposes.'[6] Problems due to electrolytic action at the practically inaccessible junctions of the copper conductors and steel hull occurred and eventually the vessel was refitted with a compete-wire system.

In 1882, the R.N.-manned troopship *Himalaya*[7] was fitted with an a.c. lighting system fed by a 650 rev/min direct-driven Siemens alternator with a belt-driven Siemens Type SD direct-current exciter. The prime mover was a three-cylinder simple-expansion Brotherhood steam engine of the type then being widely fitted for this duty although the speed of 650 rev/min was somewhat unusual. At that time few engineers saw any merit in speeds in excess of 500 rev/min due to problems with bearings and, in fact, because of commutation

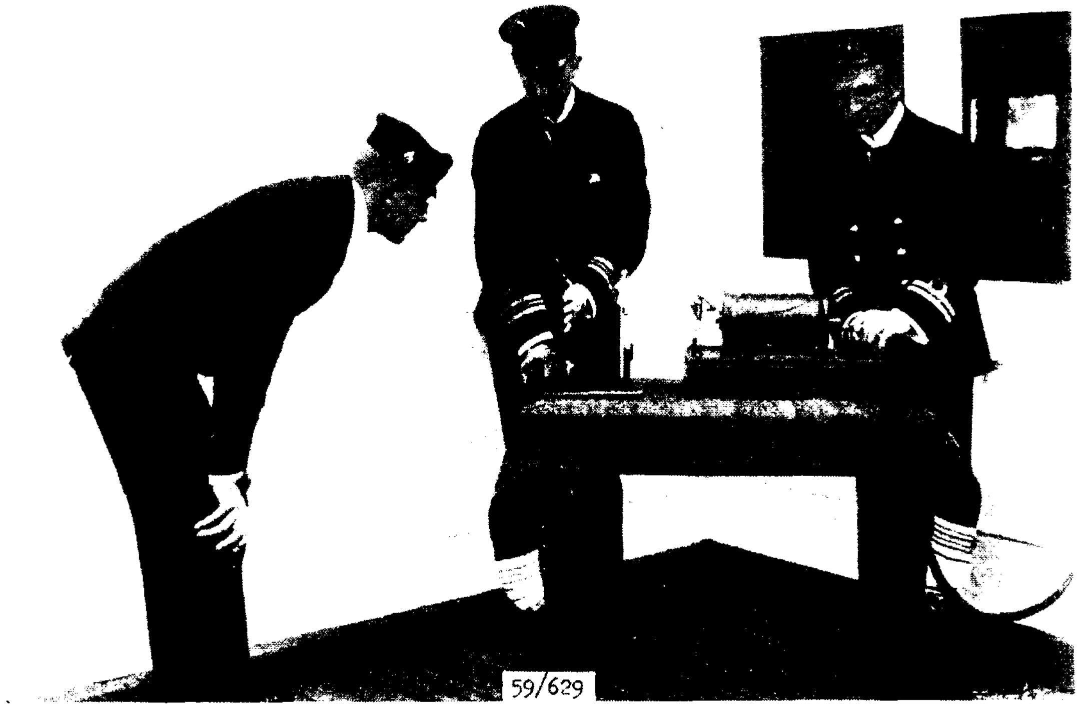


FIG. 3—INSTRUCTIONAL CLASS (POSED) AT H.M.S. 'DEFIANCE' 1896

problems such speeds were generally confined, as in this case, to a.c. machines. The a.c. system was not repeated, and the Imperial troopship *Orontes*[8] and the Indian troopers *Crocodile*, *Euphrates*, *Jumna*, *Malabar*, and *Serapis*[9] were fitted with d.c. systems in 1883, the five latter vessels having some 400 incandescent lamps apiece[10]. At a meeting of the Institution of Civil Engineers on the 11th November 1884[11], it was stated that in the *Malabar*, which was fitted with a total of 307 lamps of ten candle-power each and 139 of sixteen candle-power, the average life of those that failed between the 6th August 1883 and the 31st October 1884 was 3799 hours.

By this time incandescent lighting was being generally adopted with, of course, differences in system detail between navies. The U.S. Navy first carried out trials in the wooden-hulled screw frigate *Brooklyn*[12] in 1882 and the following year the composite-hulled *Trenton*[13] was fitted with a 110-volt 120-ampere Edison shunt-wound dynamo to supply a 238-lamp lighting system. In the R.N., by 1885, amongst others, the turret ships *Devastation*, *Thunderer*, and *Dreadnought* were fitted with W. H. Allen's 80-volt d.c. 200-lamp shunt-wound dynamos driven at 300 rev/min by compound reciprocating steam engines.

The 9150-ton battleship *Colossus*, commissioned at Portsmouth in 1886, was fitted with three searchlights which, with her general lighting installation, were supplied by three 80-volt Gramme dynamos via independent switchboards capable of being cross-connected to enable each dynamo to supply any part of the system. Normally, two machines were employed for general lighting the third being available for any one of the searchlights; at general quarters, however, two dynamos were switched over to searchlights, the ship's internal lighting load being reduced to within the capacity of the third machine.

Although this type of installation proved satisfactory from the illumination aspect, the dynamos and cables were a constant source of trouble. The cables, rubber-insulated, cotton-taped or braided, and coated with preservative varnish, were run in teak casings and embedded in putty; despite this, the ingress of salt water caused short circuits and frequently set fire to the wood casings! Early lead-sheathed cables, in which the core was insulated by four layers of jute, proved none too satisfactory but, once manufacturing problems had been

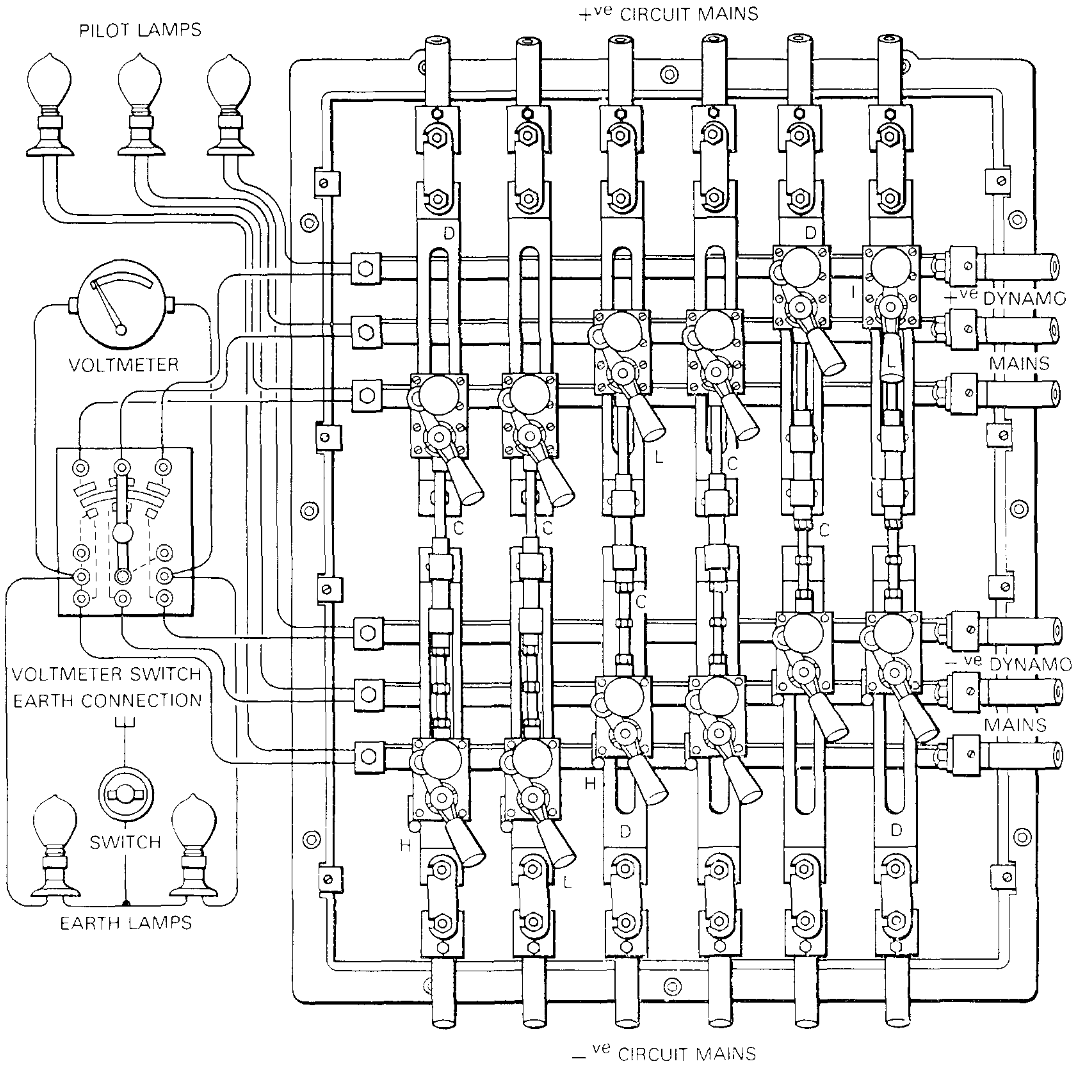


FIG. 4—THE PORTSMOUTH SWITCHBOARD WIDELY FITTED DURING THE 1890s

overcome, rubber-insulated cable with a lead sheath was introduced to service and was adopted as the standard for warships. Also, at this time, in new construction warships, the action dynamos were sited below the waterline behind armour and an additional machine, known as the 'peace or daylight' dynamo, was provided in a sheltered position on the upper deck.

Although the R.N. used several manufacturers of dynamos, in general, all machines suffered from insulation problems and excessive heating in the armature windings. These shortcomings led eventually to the design of the 'Portsmouth' dynamo by Mr. Lane of Portsmouth Dockyard. The first five machines (two of which were fitted in the 5440-ton turret ship *Rupert* then (1891) being modernized) were 80-volt d.c. 400-ampere dynamos driven at 330 rev/min by 56 ihp inverted compound steam engines. In all, engine, dynamo, and bedplate weighed no less than five and a half tons!

The 'Portsmouth' dynamo was followed by the 'Portsmouth' switchboard first fitted in 1892 in the battleship *Centurion*. In its early form, this switchboard was designed to take the output from three 400-ampere dynamos each of which could be switched through to any or all of the service circuits although the dynamos could not be worked in parallel.

The 14 500-ton first-class battleship *Royal Sovereign* with an installed capacity of 130 kilowatts was accepted into service in 1892. In this ship, amongst other things, 'clusters of glow-lamps beneath an enamelled metal reflector are also employed for lighting the deck when coaling . . . at night.' This ship was the first to be illuminated overall (outline circuits), an event which took place in 1895, which year also heralded the introduction of the bayonet lamp-holder.

In H.M.S. *Majestic* (completed in 1895) and other ships of this class the total capacity was increased to 160 kilowatts and, five years later, 100 volts d.c. was adopted as standard pressure for all new construction. By this time, electric ventilation fans had appeared and electric motors were introduced for training the 9·2-inch gun-mountings and for working the hoists in the cruisers *Powerful* and *Terrible*. The 10-inch-gunned battleships *Barfleur*, *Centurion*, and *Renown* were refitted with electric motors as an alternative power drive for gun elevating and loading. Only moderately successful due to lack of power, it had to be admitted in a contemporary manual [14] that 'Motors are already very largely employed in foreign men-of-war, and although not used to anything like the extent at present in our Navy they are, nevertheless, coming more and more into favour.'

It was the U.S.N. that led the way in introducing electric power drives. In the 9215-ton armoured cruiser *Brooklyn* (1896), two of the four twin 8-inch mountings were electrically trained (the other two being steam powered!). The electric drives proving smooth in operation, widespread adoption of electric power followed and, amongst other auxiliaries in the 11 540-ton battleships *Kearsage* and *Kentucky*, gun elevating, turret training, ammunition hoists, deck winches, boat cranes, and ventilation fans were all electric. Although these two ships operated at 80 volts d.c., a standard of 125 volts d.c. was adopted in 1905 for the cruiser *Charleston* and the following year for the battleship *Virginia*.

At this time, the installed capacity in British warships was only about half that in comparable U.S. warships. By virtue of historical precedent, the R.N. remained wedded to hydraulic machinery for large gun-mountings whilst a belief, amounting almost to an act of faith, in the unreliability of electric motor-driven equipment resulted in the retention of steam for deck machinery and other auxiliaries such as pumps, refrigerating machinery, and air compressors. The installed capacity in the 16 350-ton battleships of the KING EDWARD VII Class was 310 kW against the 800 kW of the comparable MINNESOTA Class of the U.S.N. The German and Austro-Hungarian navies built in an even greater capacity in their battleships than the U.S.N. The comparisons are given in TABLE I

TABLE I

| *Ship* | *Country* | *Date* | *d.c. volts* | *kW* |
|---|---|---|---|---|
| *Nassau* | Germany | 1909 | 220 | 1280 |
| *Erzherzog Franz Ferdinand** | Austria | 1910 | 220 | 1200 |
| *South Carolina* | U.S.A. | 1910 | 125 | 800 |
| *Bellerophon* | Britain | 1909 | 100 | 600 |
| *Dreadnought* | Britain | 1906 | 100 | 410 |

* Pre-*Dreadnought*

In all these ships, distribution was arranged on the two-wire parallel[15] switchboard system in which the dynamos were connected to the bus-bars of one or more switchboards, the latter being separated as a rule by watertight bulkheads. Supplies to the services were taken from the bus-bars via switches and fuses and thence via a 'tree' distribution little different from that in use today. Individual switchboards could be linked by hand switches and inter-connecting cables enabling any dynamo to feed all or part of the system, and the risk of disabling damage was reduced by providing alternative supplies from opposite sides of the system for all important services.

This system, adopted by the Royal Navy in 1902, permitted parallel operation of dynamos so facilitating the switching over of machines without interruption of supplies. Dynamos might also be worked continuously in parallel.

A 'Committee on Electrical Equipment of Warships' appointed by the Admiralty in 1902 reported on, amongst other subjects, the proliferation of auxiliary drives employing steam, hydraulic, and electric power in H.M. ships. In recommending a policy of standardization, the Committee noted that an electric drive appeared to offer the greatest advantage; in particular, the electric motor incorporated few moving parts whilst the routeing of electric cables posed fewer problems than the siting of steam or hydraulic pipe runs. Little attempt appears to have been made to follow up these recommendations, and ships continued to be fitted with a multiplicity of auxiliary drives in keeping with existing policy or, perhaps, a lack thereof!

To minimize voltage variations and to improve stability, the majority of warships were fitted with compound-wound dynamos provided with an equalizer connection to ensure satisfactory current sharing between the series windings of machines working in parallel. When ready for load, connection to the switchboard bus-bars was made via a hand-closed supply breaker fitted with overload, reverse-current, and under-voltage protection, the breaker movement being interlocked, where appropriate, with the equalizer switch which had necessarily to be closed first.

Smaller warships were fitted with less complex systems: a typical small cruiser of the early Dreadnought period was provided with a pair of 100-volt dynamos feeding a single parallel-type switchboard, and destroyers and below were usually equipped with a single 100-volt machine supplying the searchlight, general lighting (including machinery spaces), and a low-power (24 volts d.c.) motor generator, the latter for telephones, data transmission circuits, call-bells and the like. In harbour, of course, the boiler fires in such minor warships would be drawn and the electric plant shut down.

The quarter century between 1881 and 1906 had seen the change from an essentially simple lighting system to a flexible power and lighting system of more or less proven design and reliability. Electric-motor drives were employed extensively for a variety of tasks, and electric space heating, cooking and galley equipment, bakery equipment, and water heating were widely used, in particular by the U.S. Navy. The two-wire direct-current system was employed by all major navies although the choice of voltage differed widely.

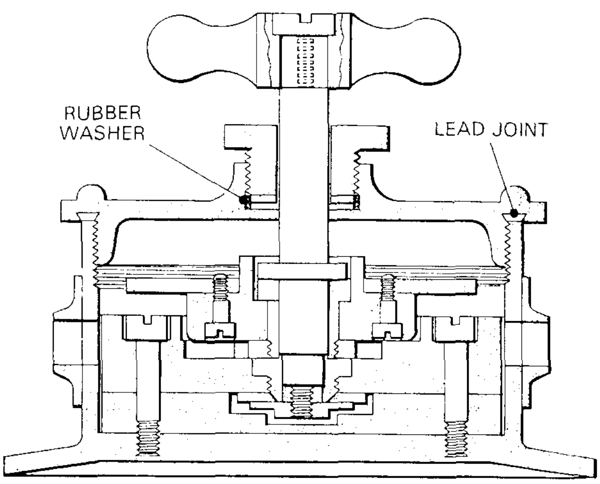


FIG. 5—WATERTIGHT SWITCH c1895

These still relatively simple direct-current switchboard systems well met the needs of the time. The rapid increase, however, in demand for power now imposed a need to seek means for improving the transmitted power/weight ratio of the electric installation. Furthermore, with the growth of the importance of electrics in the fighting capability of warships, the problem of system integrity demanded the attention of design engineers. The basic tenet in warship design is the need 'To float, to move, to fight'[16] and it was with this fundamental observation in mind that the naval architects tackled the next stage in the development of warship electrical systems.

**Ring Main Systems**

It was consideration of these basic needs—integrity and weight saving—that led Mr. C. H. Wordingham, Head of the Admiralty Electrical Engineering Department, to propose in 1904 the development of a ring-main system of distribution.

In its earliest form, the shunt-wound generators fed a common set of switchboard bus-bars at one end of the ring and the branch circuits were tapped off via electrically-operated branch-breakers sited in the same watertight subdivision as the services concerned. Supply-breakers and branch-breakers were controlled from the switchboard. The ring main itself and the tappings off to service circuits were made watertight enabling the system to function even though partially submerged. The branch-breakers were also watertight and connections to the ring main were made in compound-filled service boxes. The ring main was divided into sections by watertight ring-main disconnecting link boxes; isolation of a damaged section, however, would have been a time-consuming operation being undertaken only during after-action repair.

Even this elementary form of ring main substantially increased the integrity of the distribution system, since each service feeder was connected to the supply bus-bars in both directions. The first ships so fitted were the 17 350-ton battle-cruiser *Invincible*[17] and the 14 600-ton armoured cruiser *Defence*, both first commissioned in 1908. To allow for an increase in installed capacity, a supply pressure of 220 volts d.c. was adopted for these and later major warships although considered by some electrical engineers to be dangerously high. The same voltage, however, was adopted by the Imperial German Navy for their NASSAU Class battleships in 1909.

In the *Invincible*, the four 12-inch gun-mountings were worked electrically on the Ward Leonard principle. Comparative trials, however, showed their performance to be more sluggish than that achieved by contemporary hydraulic systems, though it seems probable that the electric drives were underpowered. In 1914, the *Invincible*'s installation was converted to align with accepted R.N. practice, involving the removal of one of the four turbo-generators to make way for a steam-driven hydraulic pumping station. It is interesting to note that electric operation of large gun-mountings had been in general use in the United States fleet with complete success since 1901.

Conpound-wound dynamos reappeared in the next generation of capital ships after *Invincible* necessitating the provision of a third ring-main cable and a third pole in the supply-breakers to carry the equalizer circuit. These complexities were, however, abandoned in favour of a reversion to shunt-wound dynamos in the ORION Class battleships of 1912. In this class, not only did the system take the form of a true ring (i.e. there were no switchboard bus-bars) but also a number of other improvements were incorporated. The dynamos were arranged two forward and two aft, each connected via its electrically-operated supply-breaker to feed its own quarter of the system, the junctions with the ring-main cables being in the form of 'T' joints. The clumsy ring-main disconnecting link boxes were replaced by disconnecting hand switches facilitating the isolation of a damaged cable section. The installed capacity in this and in the KING GEORGE V Class, which followed in 1913, totalled 600 kilowatts.

The generating plant in the battleship *Iron Duke* (1914) included a 150-kW diesel-driven generator, and two oil-driven dynamos apiece were fitted in the succeeding QUEEN ELIZABETH and ROYAL SOVEREIGN Classes; in other respects, the main features of the ORION Class ring-main arrangement were retained in all these vessels which entered service in 1915–16.

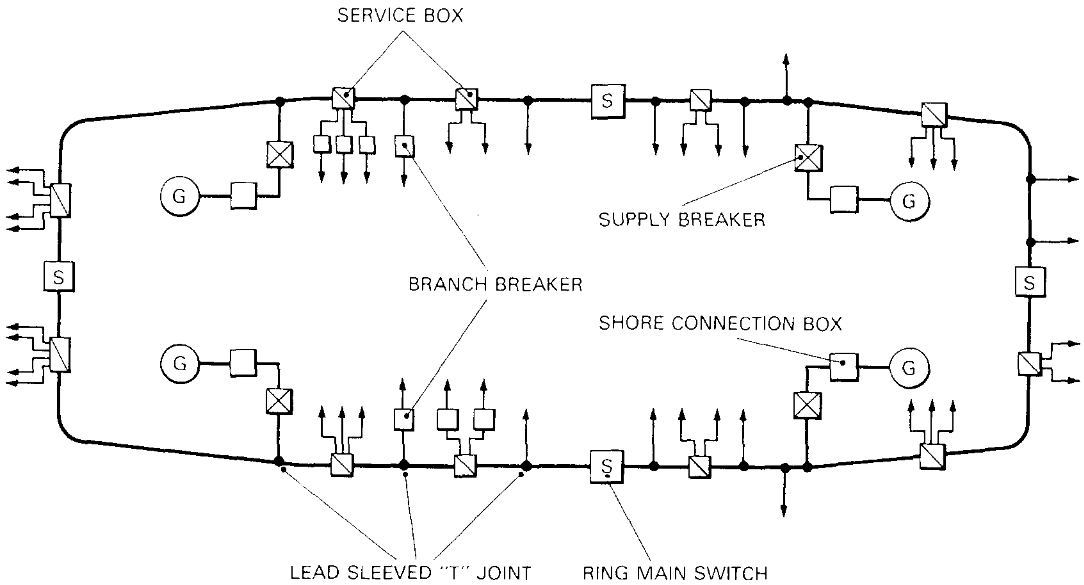


FIG. 6—RING MAIN SYSTEM—H.M.S. 'ORION' 1912

Simplified ring-main systems were fitted in British light cruisers of the period: firstly, in the 3500-ton ARETHUSA Class of 1914 which had two steam-driven dynamos, one supplying each side of the ring main at 100 volts d.c.

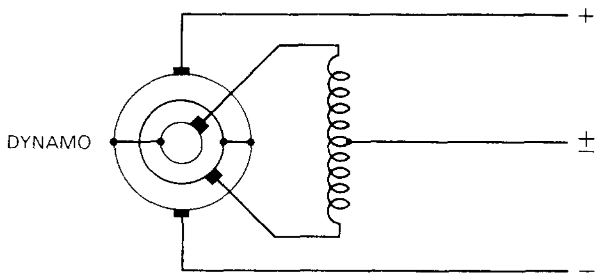


FIG. 7—SINGLE-PHASE STATIC BALANCER c1916 EMPLOYED WITH THREE-WIRE DIRECT-CURRENT SYSTEMS

Of the other major navies, only the Japanese adopted the ring-main system, presumably as a result of experience gained with the 26 320-ton battle-cruiser *Kongo* built by Vickers Ltd. at Barrow and delivered in 1913. The system followed R.N. practice and operated at a pressure of 220 volts d.c. Elsewhere, development was concentrated on improving the integrity and flexibility of proven direct-current switchboard systems with two-wire distribution usually at 220 volts[18], an exception being the U.S.N. which retained a supply pressure of 125 volts d.c. first introduced in 1905. However, in 1916, for the New York built *Arizona*, sister ship of the 31 400-ton battleship *Pennsylvania*, the U.S.N. adopted a three-wire dual-purpose d.c. system operating at 120/240 volts (with its attendant complexities). Electric motors and heating were supplied at 240 volts across the two outer conductors, and lighting, search-lights, and minor domestic services took a supply at 120 volts from between one of the two outers and the third wire.

In terms of installed capacity, the R.N. was still in 1916 at the bottom of the table; the German Navy was a long way ahead not only in utilization but also in the provision of adequate alternative oil-engined capacity.

The Germans achieved the ultimate in oil-engined capacity in the design of the battleships *Baden* and *Bayern*[19] of 1916. Although propulsion was by

TABLE II

| *Ship* | *Country* | *Date* | *Capacity* | *Generators* |
|---|---|---|---|---|
| *Konig* | Germany | 1914 | 2040 kW | 4 × 360 kW Turbo<br>2 × 300 kW Diesel |
| *Arizona* | U.S. | 1916 | 1200 kW | 4 × 300 kW Turbo |
| *Bretagne* | France | 1915 | 800 kW | 4 × 200 kW Turbo |
| *Royal Sovereign* | U.K. | 1916 | *750 kW | 2 × 200 kW Turbo<br>2 × 175 kW Diesel |

* The installation of an additional 200 kW dynamo was authorized in August 1917.

steam turbines on three shafts, the electrical installation relied entirely on diesel prime movers: there were, in fact, eight diesel dynamos with a total capacity of 24C0 kW, greater than any vessel afloat or projected at that time.

Wartime experience showed up a number of shortcomings in the design philosophy of the basic ring-main system. Isolation of damaged or faulty circuits involved much time and physical effort compounded by difficulty of access, and maintenance of the watertight integrity of the ring main—being dependent on the watertightness not only of the ring itself but also of a number of fittings including the supply and branch breakers—presented further problems. It did not become possible to take into consideration this experience and the lessons learned therefrom until the final stages of the conflict.

Considerable improvements were incorporated in H.M.S. *Hood.* The most significant change was the introduction of the mainguard—a seemingly Heath-Robinson device intended to isolate non-watertight circuits from the ring main in the event of flooding. The device comprised a carbon cylinder (or cylinders) capable of carrying the generator or branch circuit full load current and enclosed in a watertight case. Electrically-fuzed gunpowder charges mounted within each cylinder were connected across the incoming circuit via a 'flood' switch, so that in the event of flooding (salt water) the supply would be short-circuited thus firing the explosive charges to shatter the cylinders and disconnect the non-watertight circuit from the ring.

In addition, the *Hood*'s system had more subdivision of the ring main by hand switches (allowing the available generator capacity to be used more effectively in the event of damage) and emergency supply boards were provided to enable a supply to be taken direct from the generators via an emergency flexible cable system.

In all there were eight generators each of 200 kW capacity, an unusual feature being that connections at the back ends of the armatures were brought out to slip rings enabling a three-phase a.c. supply at 135 volts at 25 cycles per second to be tapped off. This was transformed up to 220 volts to supply via a three-wire unearthed system the ship's fixed submersible salvage pumps. This idea was not pursued and *Hood*'s installation remained unique.

Once the War was over, it was thought apposite to review the sum total of experience to date in order to decide the way ahead for electrical supply systems in the Royal Navy. Due consideration was given to the possible use of alternating current but it was decided that on balance the direct current system was to be preferred, operating at 220 volts for major warships and at 110 volts for destroyers and minor war vessels. In his report, presented in 1921, the then Director of Electrical Engineering, Mr. W. McClelland, considered a generator capacity of 250 kW to be the largest required for naval service and that the total installed capacity should allow one machine in excess of the number necessary to cope with the maximum action load, including adequate alternative capacity for essential services. In practice, however, this built-in redundancy was not to be achieved for many years!

*Notes:*

1. Faraday's paper was read before the Royal Society on 24th November 1831.
2. William Siemens (1823–1883): born in Lenthe, Hanover; baptized Carl Wilhelm; trained as an engineer and settled in England in 1844; naturalized 1859 and with his brothers Werner and Carl (II) established Siemens Bros. at Millbank in 1858, which firm moved to Charlton in 1866; knighted 1883, seven months before his death.
3. *Haydn's Dictionary of Dates and Universal Information* (Twentieth edition. London, 1892).
4. Built 1871 at Portsmouth Dockyard. 254 tons.
5. Built 1873. Wooden-hulled ironclad. 9100 tons.
6. *The British Navy* by Sir Thomas Brassey (London, 1882), Vol. 1, p. 475.
7. Built 1854 for Peninsular & Oriental Steam Navigation Co. but purchased by the Admiralty for service as a troopship after the outbreak of the Crimean War.
8. Iron-screw troopship built at Birkenhead, 1862. 4857 tons.
9. Built 1866–7 for the Admiralty. 4173 tons.
10. The ampere, the unit of electric current was first defined in 1881. However, no instruments were fitted in connection with these early lighting systems and the number of lamps was usually stated to indicate the total load.
11. Proceedings of the Institution of Civil Engineers, 11th November 1884.
12. Launched 1858. 3000 tons.
13. Launched 1876. 3600 tons.
14. *Torpedo Manual for His Majesty's Fleet*, Vol. 1, Magnetism, Electricity, and Electric Lighting (1901).
15. So called because it made possible the parallel operation of dynamos.
16. Motto of H.M.S. *Phoenix*, the R.N. Damage Control School, Portsmouth.
17. The other two ships of the class, namely H.M.S. *Inflexible* and H.M.S. *Indomitable*, were equipped with switchboard systems operating at 100 volts d.c.
18. The system voltage is frequently quoted as 225 volts, i.e. the voltage at the generator terminals, which allows for an estimated 5 volts line voltage drop throughout the distribution system.
19. As originally conceived, the propulsion plant of these battleships was to comprise direct-drive turbines on the two outer shafts plus a 2000 bhp diesel engine for the centre shaft, but in the event they were built with steam turbines driving all three shafts.